

**THE MISSISSIPPIAN LEADVILLE LIMESTONE
EXPLORATION PLAY, UTAH AND COLORADO –
EXPLORATION TECHNIQUES AND
STUDIES FOR INDEPENDENTS**

**SEMI-ANNUAL
TECHNICAL PROGRESS REPORT
April 1, 2006 – September 30, 2006**

by

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Utah Geological Survey,
and
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November 2006

Contract No. DE-FC26-03NT15424

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ABSTRACT

The Mississippian Leadville Limestone is a shallow, open-marine, carbonate-shelf deposit. The Leadville has produced over 53 million barrels (8.4 million m³) of oil/condensate from seven fields in the Paradox fold and fault belt of the Paradox Basin, Utah and Colorado. The environmentally sensitive, 7500-square-mile (19,400 km²) area that makes up the fold and fault belt is relatively unexplored. Only independent producers operate and continue to hunt for Leadville oil targets in the region. The overall goal of this study is to assist these independents by (1) developing and demonstrating techniques and exploration methods never tried on the Leadville, (2) targeting areas for exploration, and (3) conducting a detailed reservoir characterization study. The final results will hopefully reduce exploration costs and risks, especially in environmentally sensitive areas, and add new oil discoveries and reserves.

This report covers research and technology transfer activities for the second half of the third project year (April 1, 2006, through September 30, 2006), Budget Period II. Research consisted of completing a surface geochemical survey over the Lisbon and Lightning Draw Southeast fields, Utah, and chemical analysis of the samples.

Lisbon field is ideal for a surface geochemical survey because proven hydrocarbons underlie the area, it is easily accessible, and the surface geology is similar to the structure of the field. Proving the success of relatively low-cost geochemical surveys at Lisbon field will allow independent operators to reduce risks and minimize impacts on environmentally sensitive areas while exploring for Leadville targets. To the southwest, the recently discovered Lightning Draw Southeast field has similar geology to Lisbon field. However, the field is still near original reservoir pressure and therefore hydrocarbon microseepage to the surface may be more significant than at Lisbon field.

The geochemical survey consisted of collecting shallow soil samples over and around the fields covering the gas cap, oil leg (present only at Lisbon), and background "barren" areas to map the spatial distribution of potential surface hydrocarbon anomalies. In addition, samples were collected over oil, gas, and dry wells for analogue matching purposes and to refine the discriminant model for the fields. Approximately 400 samples were collected by the UGS along the sampling grids and around selected wells. Samples are being dried and sieved, and aliquots are now being weighed out for chemical analyses for 40 hydrocarbon compounds in the C₁-C₁₂ range, 53 major and trace elements, seven anion species, and for Synchronous Scanned Fluorescence analyses. Sample results will be plotted and contoured to identify any surficial geochemical anomalies.

In addition, a free-gas sampling program of soils was conducted over the Lightning Draw Southeast field. Results of the free-gas sampling indicate productive and non-productive areas can be distinguished based on absolute concentrations of propane, isobutane, normal butane, isopentane, normal pentane, isohexane, hydrogen, and carbon dioxide in free gas samples. Sulfate and chloride increase along suspected faults near production, which probably reflects the ascent (paleo?) of brines to the surface from the underlying Pennsylvanian Paradox Formation.

Joints in exposures of the Navajo and Entrada Sandstones may provide pathways for hydrocarbon microseepage to the surface. The sampling program was expanded to collect soil, sand, bryophytes (mosses), and lichen samples from the joints for additional hydrocarbon and elemental analysis over barren and productive parts of both Lisbon and Lightning Draw Southeast fields.

Technology transfer activities during this quarter consisted of exhibiting a booth display of project materials at the 2006 Annual Convention and Rocky Mountain Section Meeting of the American Association of Petroleum Geologists (AAPG), technical and non-technical presentations, and a publication. An abstract describing the surface geochemical survey and results was submitted to the American Association of Petroleum Geologists, for a possible presentation at the 2007 annual convention in Long Beach, California. The project home page was updated on the Utah Geological Survey Web site.

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EXECUTIVE SUMMARY

The Mississippian Leadville Limestone is a shallow, open-marine, carbonate-shelf deposit. The Leadville has produced over 53 million barrels (8.4 million m³) of oil/condensate from seven fields in the Paradox fold and fault belt of the Paradox Basin, Utah and Colorado. These fields are currently operated by small, independent producers. The environmentally sensitive, 7500-square-mile (19,400 km²) area that makes up the fold and fault belt is relatively unexplored. Only independent operators continue to hunt for Leadville oil targets in the region. The overall goal of this study is to assist these independents by (1) developing and demonstrating techniques and exploration methods never tried on the Leadville Limestone, (2) targeting areas for exploration, and (3) conducting a detailed reservoir characterization study. The final results will hopefully reduce exploration costs and risk especially in environmentally sensitive areas, and add new oil discoveries and reserves.

To achieve this goal and carry out the Leadville Limestone study, the Utah Geological Survey (UGS) and Eby Petrography & Consulting, Inc., have entered into a cooperative agreement with the U.S. Department of Energy (DOE), National Petroleum Technology Office, Tulsa, Oklahoma. The research is funded as part of the DOE Advanced and Key Oilfield Technologies for Independents (Area 2 – Exploration) Program. This report covers research and technology transfer activities for the second half of the third project year (April 1, 2006, through September 30, 2006), Budget Period II. Research consisted of completing a surface geochemical survey over the Lisbon and Lightning Draw Southeast fields, Utah, and chemical analysis of the samples.

Surface geochemical surveys have proved helpful in identifying areas of poorly drained or by-passed oil in other basins. Lisbon field is ideal for a surface geochemical survey because proven hydrocarbons underlie the area, it is easily accessible, and the surface geology is similar to the structure of the field. Lisbon field is the largest Leadville producer in Utah and is still actively producing oil and gas. The surface geology at Lisbon field consists of a major anticline along a large normal fault. Proving the success of relatively low-cost geochemical surveys at Lisbon field will allow independent operators to reduce risks and minimize impacts on environmentally sensitive areas while exploring for Leadville targets.

The geochemical survey consisted of collecting about 200 shallow soil samples at 1500-foot intervals (500 m) over and around the Lisbon field on a 16-square-mile (42 km²) rectangular grid to map the spatial distribution of potential surface hydrocarbon anomalies. The sampling grid extends beyond the proven limits of Lisbon field to establish background readings. The area chosen sufficiently covers the gas cap, oil leg, and background "barren" areas. In addition, 90 samples were collected over oil (two), gas (two), and barren dry wells (two), 15 samples at each well site, for analogue matching purposes and to refine the discriminant model for Lisbon field.

To the southwest, the recently discovered Lightning Draw Southeast field has similar geology to Lisbon field, both in terms of structure and a Leadville reservoir. It consists of two producing wells, primarily gas and condensate, along with barren dry wells off structure. However, the field is still near original reservoir pressure and therefore hydrocarbon microseepage to the surface may be more significant than at Lisbon field. The surface geochemical survey was expanded to include this new field and the surrounding area with 45 samples also collected around both the producing wells and barren dry wells. About 80 samples were collected along northwest-southeast and northeast-southwest grid lines.

Samples are being dried and sieved, and aliquots are now being weighed out for chemical analyses for 40 hydrocarbon compounds in the C₁-C₁₂ range, 53 major and trace elements, seven anion species, and for Synchronous Scanned Fluorescence analyses. Sample results will be plotted and contoured to identify any surficial geochemical anomalies.

In addition, a free-gas sampling program of soils was conducted over the Lightning Draw Southeast field. Results of the free-gas sampling indicate productive and non-productive areas can be distinguished based on absolute concentrations of propane, isobutane, normal butane, isopentane, normal pentane, isohexane, hydrogen, and carbon dioxide in free gas samples. Microseepage in soils is also different in terms of Synchronous Scanned Fluorescence spectral patterns. The discriminant function separating microseepage over productive and non-productive areas correctly predicts the location of the new production southwest of Lisbon at Lightning Draw Southeast field. Sulfate and chloride increase along suspected faults near production, which probably reflects the ascent (paleo?) of brines to the surface from the underlying Pennsylvanian Paradox Formation.

Joints in exposures of the Navajo and Entrada Sandstones may provide pathways for hydrocarbon microseepage to the surface. The sampling program was further expanded to collect soil, sand, bryophytes (mosses), and lichen samples (over 60) from the joints for additional hydrocarbon and elemental analysis over barren and productive parts of both Lisbon and Lightning Draw Southeast fields.

Technology transfer activities for the reporting period consisted of convention booth displays, technical presentations, and a publication. Project materials, plans, objectives, and results were displayed at the Utah Geological Survey booth during the American Association of Petroleum Geologists (AAPG) Annual Convention, April 9-12, 2006, in Houston, Texas, and at the AAPG Rocky Mountain Section Meeting, June 10-13, 2006, in Billings, Montana. The presentations, made at the San Juan County (Utah) Commission monthly public hearing and Interstate Oil & Gas Compact Commission Midyear Issues Summit, summarizing the project objectives and results thus far. Project team members published a Semi-Annual Technical Progress Report detailing project work, results, and recommendations. The project home page was updated on the Utah Geological Survey Web site. An abstract describing the surface geochemical survey and results was submitted to the AAPG, for a possible presentation at the 2007 Annual Convention in Long Beach, California.

INTRODUCTION

Project Overview

The Mississippian Leadville Limestone has produced over 53 million barrels (bbls) (8.4 million m³) of oil/condensate from seven fields in the northern Paradox Basin region, referred to as the Paradox fold and fault belt, of Utah and Colorado. All of these fields are currently operated by small, independent producers. There have been no new discoveries since the early 1960s, and only independent producers continue to explore for Leadville oil targets in the region, 85 percent of which is under the stewardship of the federal government. This environmentally sensitive, 7500-square-mile (19,400 km²) area is relatively unexplored with only about 100 exploratory wells that penetrated the Leadville (less than one well per township), and thus the potential for new discoveries remains great.

The overall goals of this study are to (1) develop and demonstrate techniques and exploration methods never tried on the Leadville Limestone, (2) target areas for exploration, (3) increase deliverability from new and old Leadville fields through detailed reservoir characterization, (4) reduce exploration costs and risk especially in environmentally sensitive areas, and (5) add new oil discoveries and reserves.

The Utah Geological Survey (UGS) and Eby Petrography & Consulting, Inc., have entered into a cooperative agreement with the U.S. Department of Energy (DOE) as part of its Advanced and Key Oilfield Technologies for Independents (Area 2 – Exploration) Program. The project is being conducted in two phases, each with specific objectives and separated by a continue-stop decision point based on results as of the end of Phase I (Budget Period I). The objective of Phase I was to conduct a case study of the Leadville reservoir at Lisbon field (the largest Leadville oil producer in the Paradox Basin), San Juan County, Utah, in order to understand the reservoir characteristics and facies that can be applied regionally. Phase I has been completed and Phase II (Budget Period II) approved by DOE. The first objective of Phase II will be to conduct a low-cost field demonstration of new exploration technologies to identify potential Leadville oil migration directions (evaluating the middle Paleozoic hydrodynamic pressure regime), and surface geochemical anomalies, especially in environmentally sensitive areas. The second objective will be to determine regional facies (evaluating cores, geophysical well logs, outcrop and modern analogs), identify potential oil-prone areas based on shows (using low-cost epifluorescence techniques), and target areas for Leadville exploration.

These objectives are designed to assist the independent producers and explorers who have limited financial and personnel resources. All project maps, studies, and results will be publicly available in digital (interactive, menu-driven products on compact disc) or hard-copy format and presented to the petroleum industry through a proven technology transfer plan. The technology transfer plan includes a Technical Advisory Board composed of industry representatives operating in the Paradox Basin and a Stake Holders Board composed of representatives of state and federal government agencies, and groups with a financial interest within the study area. Project results will also be disseminated via the UGS Web site, technical workshops and seminars, field trips, technical presentations at national and regional professional meetings, convention displays, and papers in various technical or trade journals, and UGS publications.

This report covers research and technology transfer activities for the second half of the third project year (April 1, 2006, through September 30, 2006), Budget Period II. Research

consisted of completing a surface geochemical survey over the Lisbon (the project case-study field in Phase I) and Lightning Draw Southeast fields, Utah, and chemical analysis of the samples.

Project Benefits and Potential Application

Exploring for the Leadville Limestone is high risk, with less than a 10 percent chance of success based on the drilling history of the region. Prospect definition requires expensive, three-dimensional (3D) seismic acquisition, often in environmentally sensitive areas. These facts make exploring difficult for independents that have limited funds available to try new, unproven techniques that might increase the chance of successfully discovering oil. We believe that one or more of the project activities will reduce the risk taken by an independent producer in looking for Leadville oil, not only in exploring but in trying new techniques. For example, the independent would not likely attempt surface geochemical surveys without first knowing they have been proven successful in the region. If we can prove geochemical surveys are an effective technique in environmentally sensitive areas, the independent will save both time and money exploring for Leadville oil.

Another problem in exploring for oil in the Leadville Limestone is the lack of published or publicly available geologic and reservoir information, such as regional facies maps, complete reservoir characterization studies, surface geochemical surveys, regional hydrodynamic pressure regime maps, and oil show data and migration interpretations. Acquiring this information or producing these studies would save cash and manpower resources which independents simply do not possess or normally have available only for drilling. The technology, maps, and studies generated from this project will help independents to identify or eliminate areas and exploration targets prior to spending significant financial resources on seismic data acquisition and environmental litigation, and therefore increase the chance of successfully finding new accumulations of Leadville oil.

These benefits may also apply to other high-risk, sparsely drilled basins or regions where there are potential shallow-marine carbonate reservoirs equivalent to the Mississippian Leadville Limestone. These areas include the Utah-Wyoming-Montana thrust belt (Madison Limestone), the Kaiparowits Basin in southern Utah (Redwall Limestone), the Basin and Range Province of Nevada and western Utah (various Mississippian and other Paleozoic units), and the Eagle Basin of Colorado (various Mississippian and other Paleozoic units).

Many mature basins have productive carbonate reservoirs of shallow-marine shelf origin. These mature basins include the Eastern Shelf of the Midland Basin, West Texas (Pennsylvanian-age reservoirs in the Strawn, Canyon, and Cisco Formations); the Permian Basin, West Texas and southeast New Mexico (Permian age Abo and other formations along the northwest shelf of the Permian Basin); and the Illinois Basin (various Silurian units). A successful demonstration in the Paradox Basin makes it very likely that the same techniques could be applied in other basins as well. In general, the average field size in these other mature basins is larger than fields in the Paradox Basin. Even though there are differences in depositional facies and structural styles between the Paradox Basin and other basins, the fundamental use of the techniques and methods is a critical commonality.

PARADOX BASIN - OVERVIEW

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado, with a small portion in northeastern Arizona and northwestern New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast-trending, evaporitic basin that predominately developed during the Pennsylvanian. The basin can generally be divided into three areas: the Paradox fold and fault belt in the north, the Blanding sub-basin in the south-southwest, and the Aneth platform in southeasternmost Utah (figure 1). The Mississippian Leadville Limestone is one of two, major oil and gas reservoirs in the Paradox Basin, the other being the Pennsylvanian Paradox Formation (figure 2); minor amounts of oil are produced from the Devonian McCracken Sandstone at Lisbon field. Most Leadville production is from the Paradox fold and fault belt (figure 3).

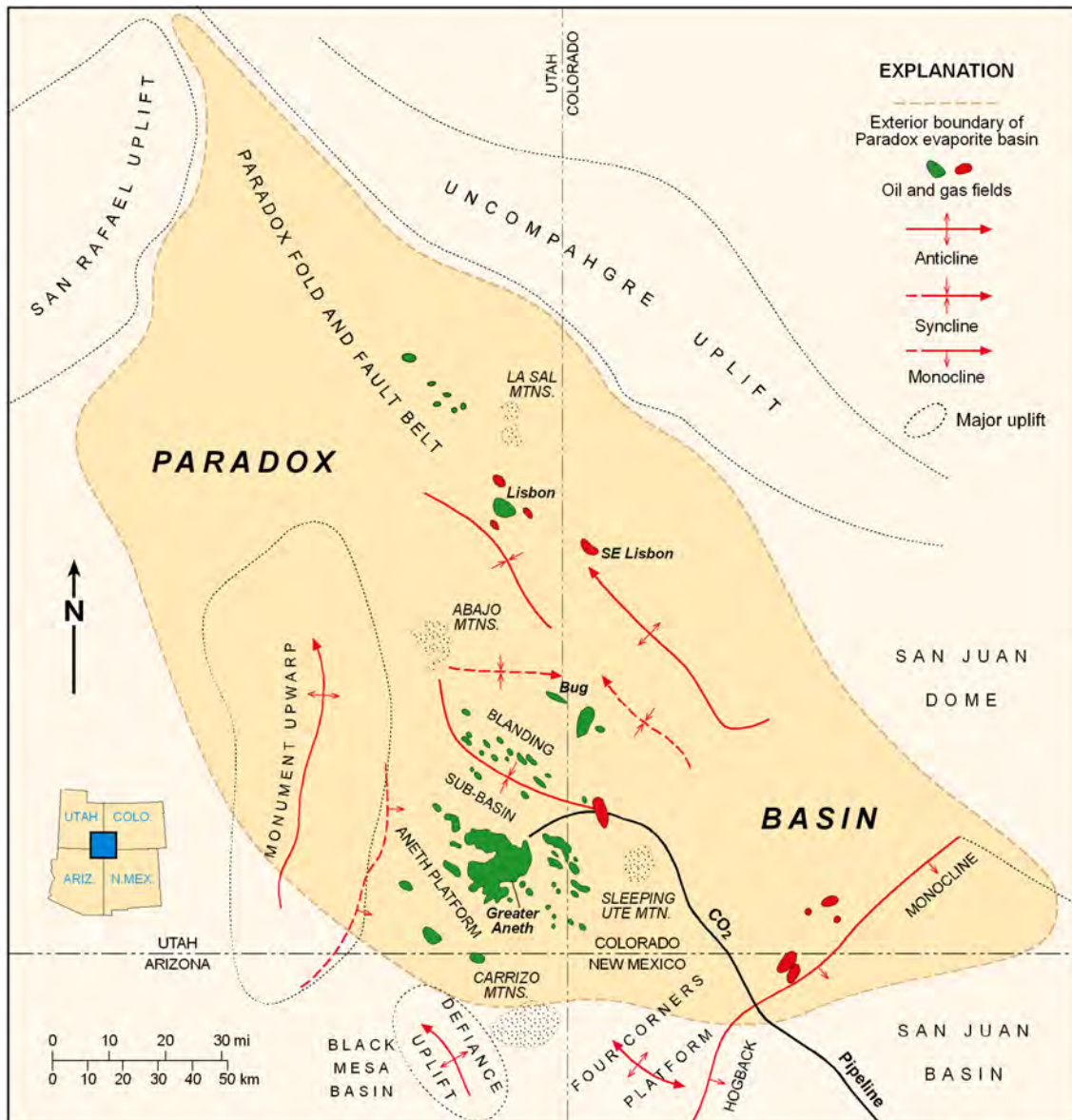


Figure 1. Oil and gas fields in the Paradox Basin of Utah and Colorado.

PENN	Hermosa Group	Paradox Fm	2000-5000'		potash & salt
		Pinkerton Trail Fm	0-150'		
	Molas Formation		0-100'		
M	Leadville Limestone		300-600'		
DEV	Ouray Limestone		0-150'		
	Elbert Formation		100-200'		
	McCracken Ss M		25-100'		
Є	"Lynch" Dolomite		800-1000'		

Oil and gas production; Condensate and oil production

Figure 2. Stratigraphic column of a portion of the Paleozoic section determined from subsurface well data in the Paradox fold and fault belt, Grand and San Juan Counties, Utah (modified from Hintze, 1993).

The most obvious structural features in the basin are the spectacular anticlines that extend for miles in the northwesterly trending fold and fault belt. The events that caused these and many other structural features to form began in the Proterozoic, when movement initiated on high-angle basement faults and fractures 1700 to 1600 Ma (Stevenson and Baars, 1987). During Cambrian through Mississippian time, this region, as well as most of eastern Utah, was the site of typical, thin, marine deposition on the craton while thick deposits accumulated in the miogeocline to the west (Hintze, 1993). However, major changes occurred beginning in the Pennsylvanian. A series of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The southwestern flank of the Uncompahgre Highlands (uplift) is bounded by a large, basement-involved, high-angle, reverse fault identified from seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest – the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993).

The Paradox Basin is surrounded by other uplifts and basins, which formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1). The Paradox fold and fault belt was created during the Tertiary and Quaternary by a combination of (1) reactivation of basement normal faults, (2) salt flowage, dissolution, and collapse, and (3) regional uplift (Doelling, 2000). Outcrops ranging in age from Pennsylvanian through Cretaceous, with surficial Quaternary deposits, are found within the Paradox Basin.

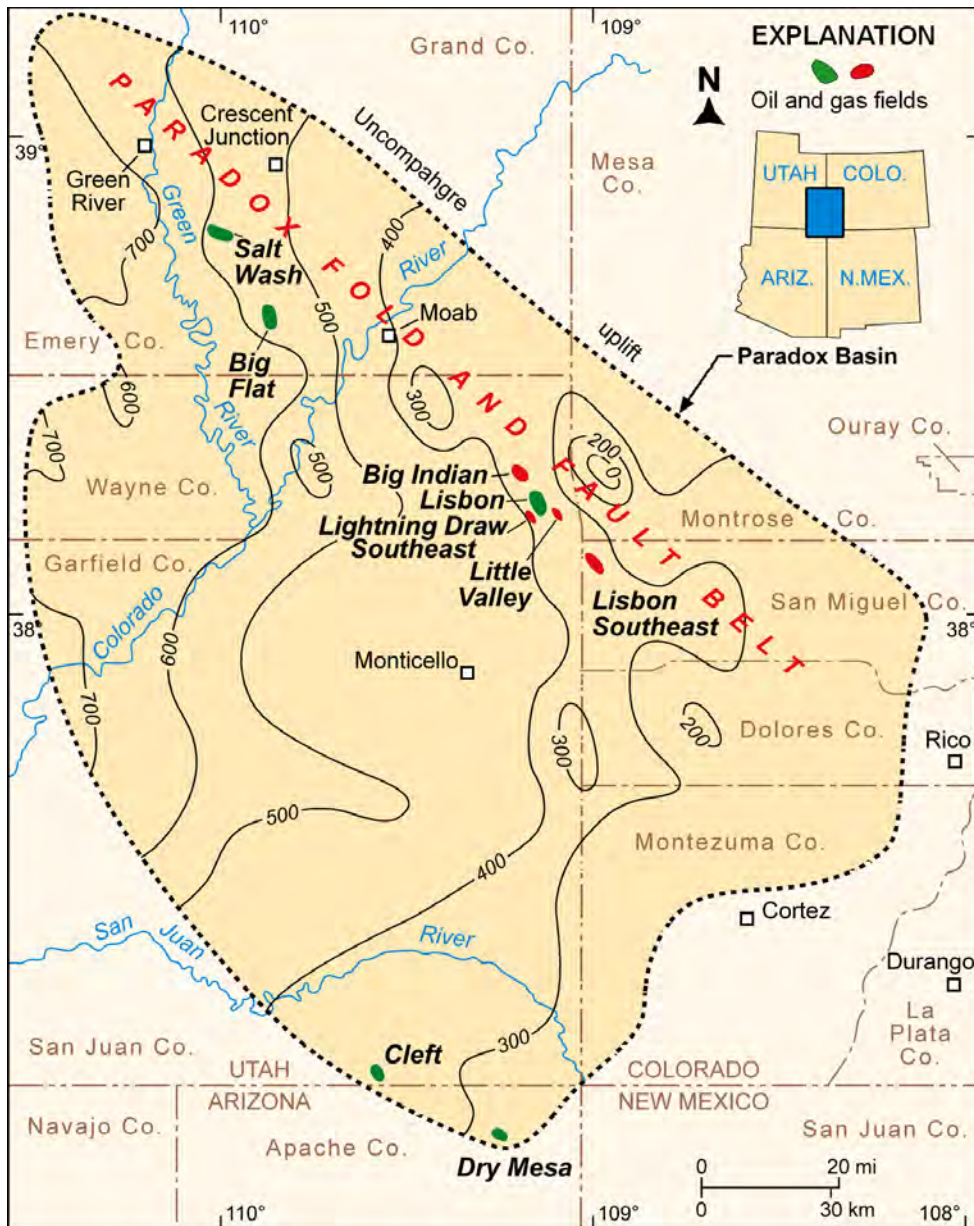


Figure 3. Location of fields that produce from the Mississippian Leadville Limestone, Utah and Colorado. Thickness of the Leadville is shown; contour interval is 100 feet (modified from Parker and Roberts, 1963).

Most oil and gas produced from the Leadville Limestone is found in basement-involved, northwest-trending structural traps with closure on both anticlines and faults (figure 4). Lisbon, Big Indian, Little Valley, Lightning Draw Southeast, and Lisbon Southeast fields (figure 3) are sharply folded anticlines that close against the Lisbon or nearby fault zones. Salt Wash and Big Flat fields (figure 3), northwest of the Lisbon area, are unfaulted, east-west- and north-south-trending anticlines, respectively.

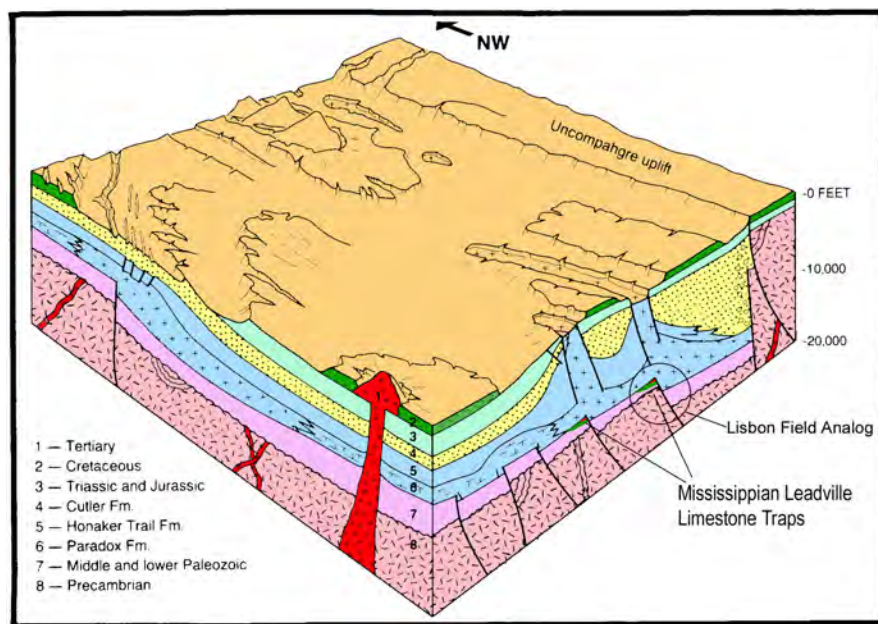


Figure 4. Schematic block diagram of the Paradox Basin displaying basement-involved structural trapping mechanisms for the Leadville Limestone fields (modified from Petroleum Information, 1984; original drawing by J.A. Fallin).

SURFACE GEOCHEMICAL SURVEY IN THE LISBON CASE-STUDY FIELD AND LIGHTNING DRAW SOUTHEAST FIELD AREA, SAN JUAN COUNTY, UTAH – RESULTS AND DISCUSSION

Introduction

Surface exploration methods, such as geochemical, magnetic, and remote sensing, have increasingly proven to significantly reduce petroleum exploration risks and finding costs. These methods, and numerous case histories, are summarized by Schumacher and LeSchack (2002). Surface geochemical surveys in the Michigan and Williston Basins helped identify areas of poorly drained or by-passed oil in pinnacle reef fields (Wood and others, 2001, 2002), which are comparable in many aspects to the depositional environment of the Leadville Limestone in the Paradox Basin. Surface geochemical methods detected hydrocarbon microseepage over Grant Canyon field, Nevada, and these methods are also being used to define potential faulted, carbonate reservoirs in western Utah (Seneshen and others, 2006). Surface geochemical surveys represent a fast, low-cost alternative to 3D seismic acquisition, especially in environmentally sensitive areas with extensive outcrops such as the Paradox Basin. Anomalies are relatively easy to identify and are conclusive.

Lisbon field, San Juan County, Utah (figures 1 and 3) accounts for most of the Leadville oil production in the Paradox Basin. A wealth of Lisbon core, petrographic, and other data is available to the UGS. The reservoir characteristics, particularly diagenetic overprinting and history, and Leadville facies can be applied regionally to other fields and exploration trends in the Paradox Basin. Therefore, we selected Lisbon as the major case-study field for the Leadville Limestone project. Lisbon field is also ideal for a surface geochemical survey. Besides active hydrocarbon production from beneath easily the accessible area, the surface geology is similar to the subsurface structure of the field (figures 5 and 6). A major northwest-southeast-trending anticline (tens of miles in length) along the Lisbon fault, displaces the Pennsylvanian Honaker Trail Formation against Cretaceous strata.

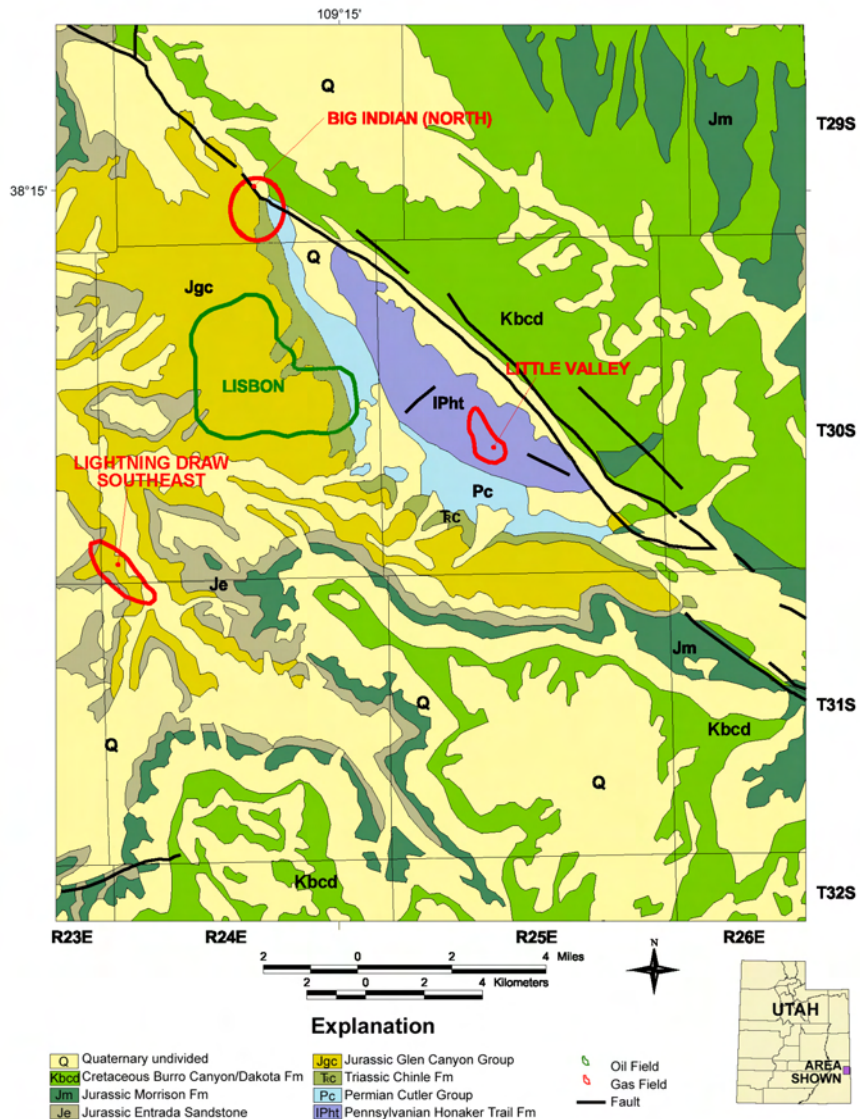


Figure 5. General surface geology of the Lisbon field area. Modified from Hintze and others (2000).

The recently discovered Lightning Draw Southeast field (figures 1 and 3) has similar geology to Lisbon field, both in terms of structure and a Leadville reservoir. It consists of two productive wells, primarily gas and condensate, along with barren dry wells off structure (figure 7). However, the Lightning Draw Southeast field is still near original reservoir pressure and therefore hydrocarbon microseepage to the surface may be more significant than at Lisbon field to the northeast.

The Leadville reservoirs in Lisbon and Lightning Draw Southeast fields are separated from upper Paleozoic and Mesozoic strata by cyclic evaporites in the Pennsylvanian Paradox Formation. These conditions are typical of what might be expected when exploring for similar drilling targets in the basin. Three factors create reservoir heterogeneity within productive zones: (1) variations in carbonate fabrics and facies, (2) diagenesis (including karstification and late-stage bitumen plugging), and (3) fracturing. The extent of these factors and how they are combined affect the degree to which they create barriers to fluid flow.

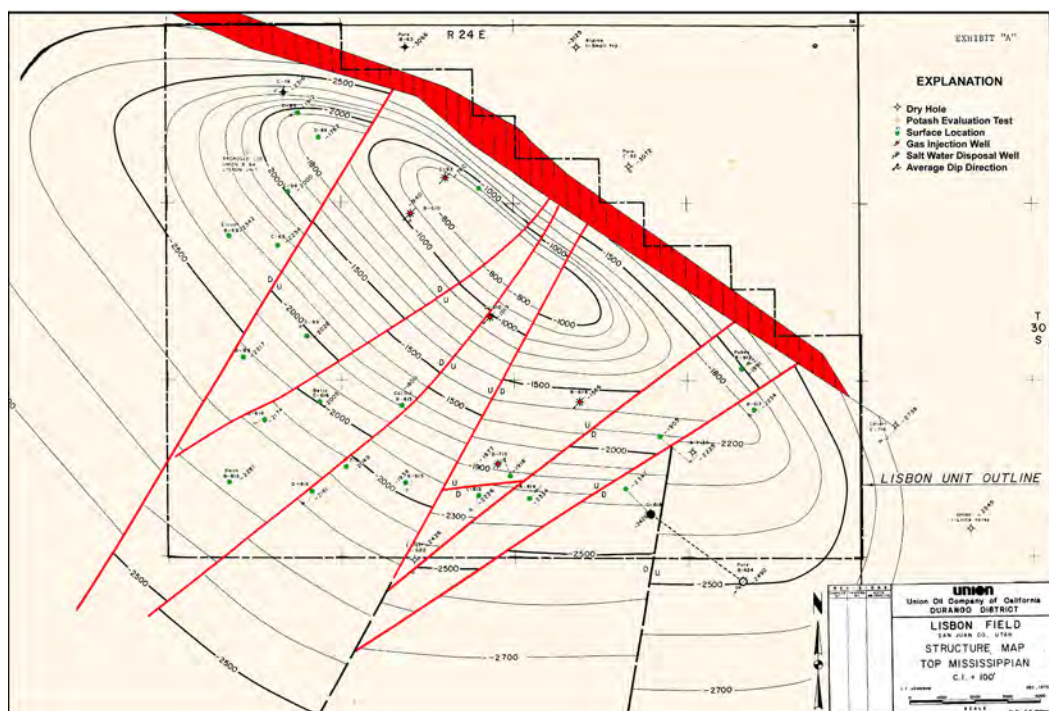


Figure 6. Top of structure of the Leadville Limestone, Lisbon field, San Juan County, Utah (modified from C.F. Johnson, Union Oil Company of California files, 1970; courtesy of Tom Brown, Inc.).

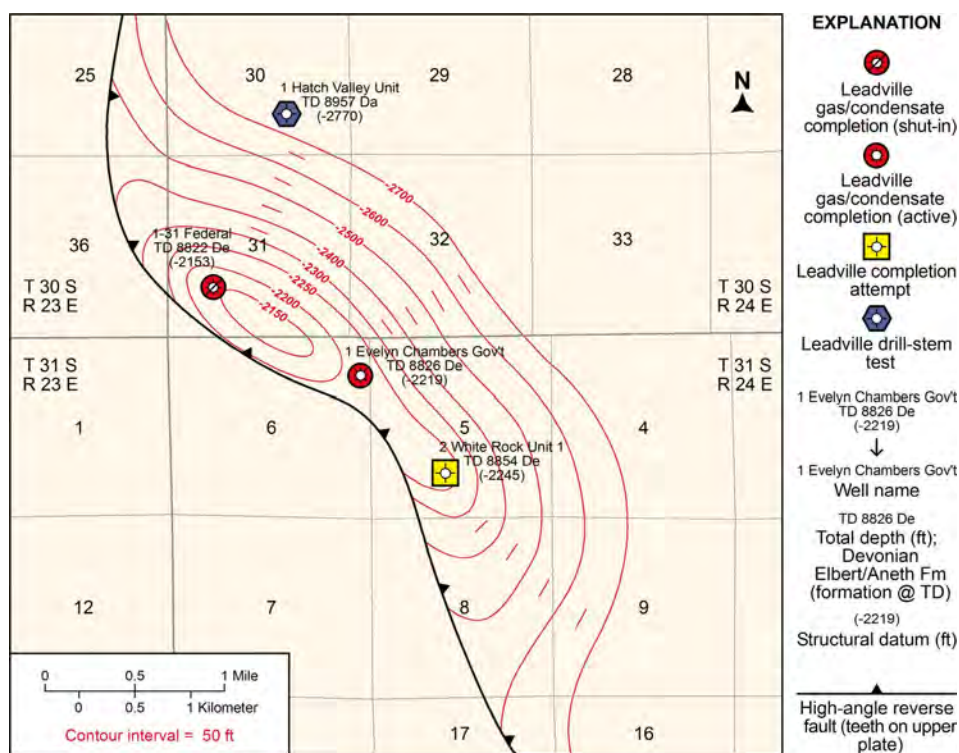


Figure 7. Top of structure of the Leadville Limestone, Lightning Draw Southeast field, San Juan County, Utah (modified from a fault map provided courtesy of ST Oil Company).

The UGS contracted with Direct Geochemical of Golden, Colorado, to train UGS staff to conduct the sampling program; sample analysis and interpretation are being conducted by Direct Geochemical. This low-cost (around \$150 per sample) surface geochemical survey began at Lisbon field in March 2006.

Lisbon Field Synopsis

The Lisbon trap is an elongate, asymmetric, northwest-trending anticline, with nearly 2000 feet (600 m) of structural closure and bounded on the northeast flank by a major, basement-involved normal fault with over 2500 feet (760 m) of displacement (Smith and Prather, 1981) (figure 6). Several minor, northeast-trending normal faults divide the Lisbon Leadville reservoir into segments.

Producing units in Lisbon field contain dolomitized crinoidal/skeletal grainstone, packstone, and wackestone fabrics. Diagenesis includes fracturing, autobrecciation, karst development, hydrothermal dolomite, and bitumen plugging. The net reservoir thickness is 225 feet (69 m) over a 5120-acre (2100 ha) area (Clark, 1978; Smouse, 1993). Reservoir quality is greatly improved by natural fracture systems associated with the Paradox fold and fault belt. Porosity averages 6 percent in intercrystalline and moldic networks enhanced by fractures; permeability averages 22 millidarcies (mD). The drive mechanism is an expanding gas cap and gravity drainage; water saturation is 39 percent (Clark, 1978; Smouse, 1993). The bottom-hole temperature ranges from 133 to 189°F (56-87°C).

Lisbon field was discovered in 1960 with the completion of the Pure Oil Company No. 1 NW Lisbon USA well, NE1/4NW1/4 section 10, T. 30 S., R. 24 E., Salt Lake Base Line and Meridian (SLBL&M) (figure 6), with an initial flowing potential (IFP) of 179 bbls of oil per day (BOPD) (28 m³) and 4376 thousand cubic feet of gas per day (MCFGPD [124 MCMPD]). The original reservoir field pressure was 2982 pounds per square inch (psi [20,560 kPa]) (Clark, 1978). There are currently 22 producing (or shut-in wells), 11 abandoned producers, five injection wells (four gas injection wells and one water/gas injection well), and four dry holes in the field. Cumulative production as of June 1, 2006, was 51,148,015 bbls of oil (8,132,534 m³), 786.5 billion cubic feet of gas (BCFG [22.3 BCMG]) (cycled gas), and 50,115,555 bbls of water (BW [7,968,373 m³]) (Utah Division of Oil, Gas and Mining, 2006). Gas that was re-injected into the crest of the structure to control pressure decline is now being produced.

Lightning Draw Southeast Field Synopsis

Like the Lisbon trap, the Lightning Draw Southeast trap is also an elongate but relatively small, asymmetric, northwest-trending anticline (no surface expression), with nearly 250 feet (75 m) of structural closure. However, the structure is bounded on the southwest flank by a high-angle, basement-involved reverse fault (figure 7). A northwest-trending syncline separates the Lightning Draw Southeast and Lisbon anticlines in the subsurface.

Producing units are similar to Lisbon field in terms of depositional environments, carbonate fabrics, and diagenesis. There are two principal Leadville zones at Lightning Draw Southeast field: an upper zone primarily of fossiliferous limestone with crinoids, brachiopods, and coated grains forming skeletal wackestone to packstone and some grainstone fabrics), and a lower zone of dolomitized mudstone with large rhombic to sucrosic dolomite crystals. Diagenesis consists of hydrothermal dolomitization, bitumen coating, and fracturing. The

producing interval is confined to the upper zone although both have porosity units over 6 percent. The net reservoir thickness is about 40 feet (12 m) over an approximate 320-acre (130 ha) area. Porosity over the perforated interval averages 17 percent, and permeability averages 13 mD. The drive mechanism is an expanding gas cap; water saturation is 21 percent. The bottom-hole temperature is 136°F (58°C).

The Leadville Limestone reservoir at Lightning Draw Southeast field was discovered in 2004 with the completion of the ST Oil Company Federal No. 1-31 well, NW1/4SW1/4 section 31, T. 30 S., R. 24 E., SLBL&M (figure 7), with an IFP of 18 bbls of condensate per day (BCPD [3 m³]), 1543 MCGPD (44 MCMPD), and 5 BW per day (0.8 m³) (production from the Pennsylvanian Paradox Formation [Ismay zone] was established in 1980 by Texaco). The API gravity of the condensate is 50°. The original reservoir field pressure was 1100 psi (7585 kPa). There is currently one producing and one shut-in gas/condensate well in the field. Cumulative production as of June 1, 2006, was 1863 bbls of condensate (296 m³), 197,527 MCFG (5594 MCMG), and 2181 BW (347 m³) (Utah Division of Oil, Gas and Mining, 2006).

Jointing

Joints in outcrops may provide pathways for hydrocarbon microseepage to the surface (figure 8). Thus, the sampling program was further expanded to collect sand and soil samples from the joints for additional hydrocarbon and elemental analysis over barren and productive parts of both Lisbon and Lightning Draw Southeast fields.

Bryophytes (mosses) and lichen commonly grow along thin joints in the area where there are higher amounts of moisture (figure 9). They may also show a geochemical signature in their tissues indicative of hydrocarbons or subsurface mineralization, so they were also sampled to compare with the soil analysis results. Two species of bryophytes and one species of lichen grow along joints in the area. The bryophytes fit into the genera *Grimmia* (possibly *Grimmia wrightii*) and *Bryum*. Both are common soil crust mosses. The lichen is *Collema tenax* – an abundant and common soil crust lichen in the intermountain western United States (Larry St. Clair, Monte L. Bean Life Science Museum, Brigham Young University, written communication, October 28, 2006).

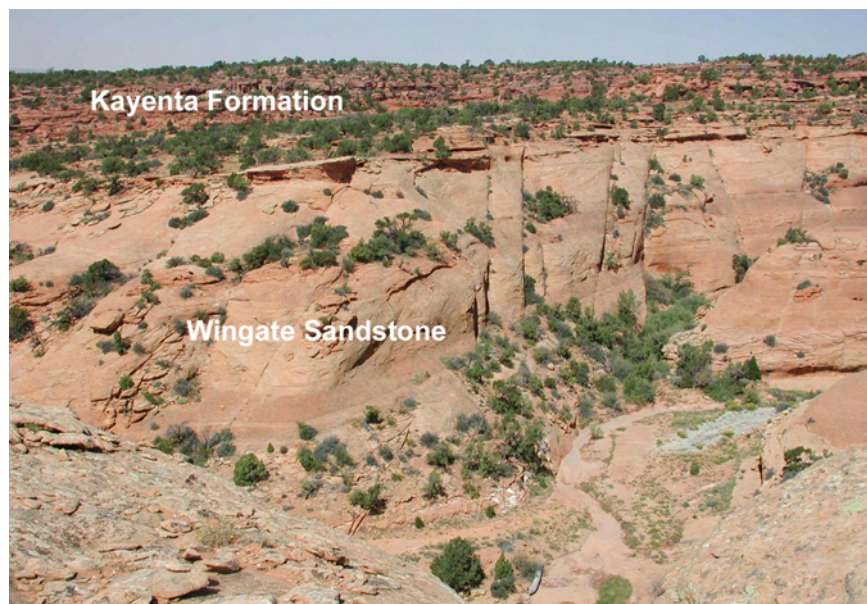


Figure 8. Joints dipping at various angles in the Jurassic Wingate Sandstone near the Lisbon No. B-610 well (NE1/4NW1/4 section 10, T. 30 S., R. 24 E., SLBL&M) over the gas cap of Lisbon field; view to the northwest. Note that the continuation of these joints into the overlying Jurassic Kayenta Formation is not as obvious.



Figure 9. Bryophytes (mosses) and lichen that commonly grow along thin, moisture-rich joints in sandstone outcrops in the Lisbon area. (A) Close-up of bryophytes (*Grimmia* [possibly *Grimmia wrightii*] and *Bryum*) and lichen (*Collema tenax*) along a joint in the Wingate Sandstone near the Lisbon No. D-810 (NW Lisbon USA No. A-2) well (NE1/4SE1/4 section 10, T. 30 S., R. 24 E., SLBL&M) over the gas cap of Lisbon field. (B) Bryophytes and lichen along a thin joint in the Jurassic Navajo Sandstone over the oil leg of Lisbon field. The Lisbon No. D-716 well (SE1/4NE1/4 section 16, T. 30 S., R. 24 E., SLBL&M) and southwest dipping flank of the Lisbon anticline (Kayenta Formation) are in the background. (C) Bryophytes and lichen along curvilinear, polygonal joints in the Navajo Sandstone near the No. 21-4 Federal well (NW1/4NW1/4 section 21, T. 30 S., R. 24 E., SLBL&M) over the water leg of Lisbon field.

Jointing is best developed in the Jurassic Wingate and Navajo Sandstones, and is also present in the intervening Kayenta Formation although not as pronounced. Joints may be thin (millimeter to centimeter) or several feet in width (figures 9 and 10A, respectively) and tens of feet or miles in length. They may also occur as (1) parallel (figure 8), (2) curvilinear polygonal, often with several orders of size or generation (figure 9C), and (3) blocky or rectilinear joint sets (figure 10B). Joint sets in the area generally are vertical to near vertical. Many small joints contain very little soil, although enough to support bryophytes and lichen growth where there is sufficient moisture (figures 9 and 10B). Some small joints are filled with thin (a few millimeters) silica or calcite veins (figure 10C); those joints observed over the gas cap area near the Lisbon No. C-910 well (SW1/4SE1/4 section 10, T. 30 S., R. 24 E., SLBL&M) have halos of possible iron/manganese-bearing minerals around calcite (figure 10D). Large joint sets often contain brecciated sandstone and fault gouge-like material.

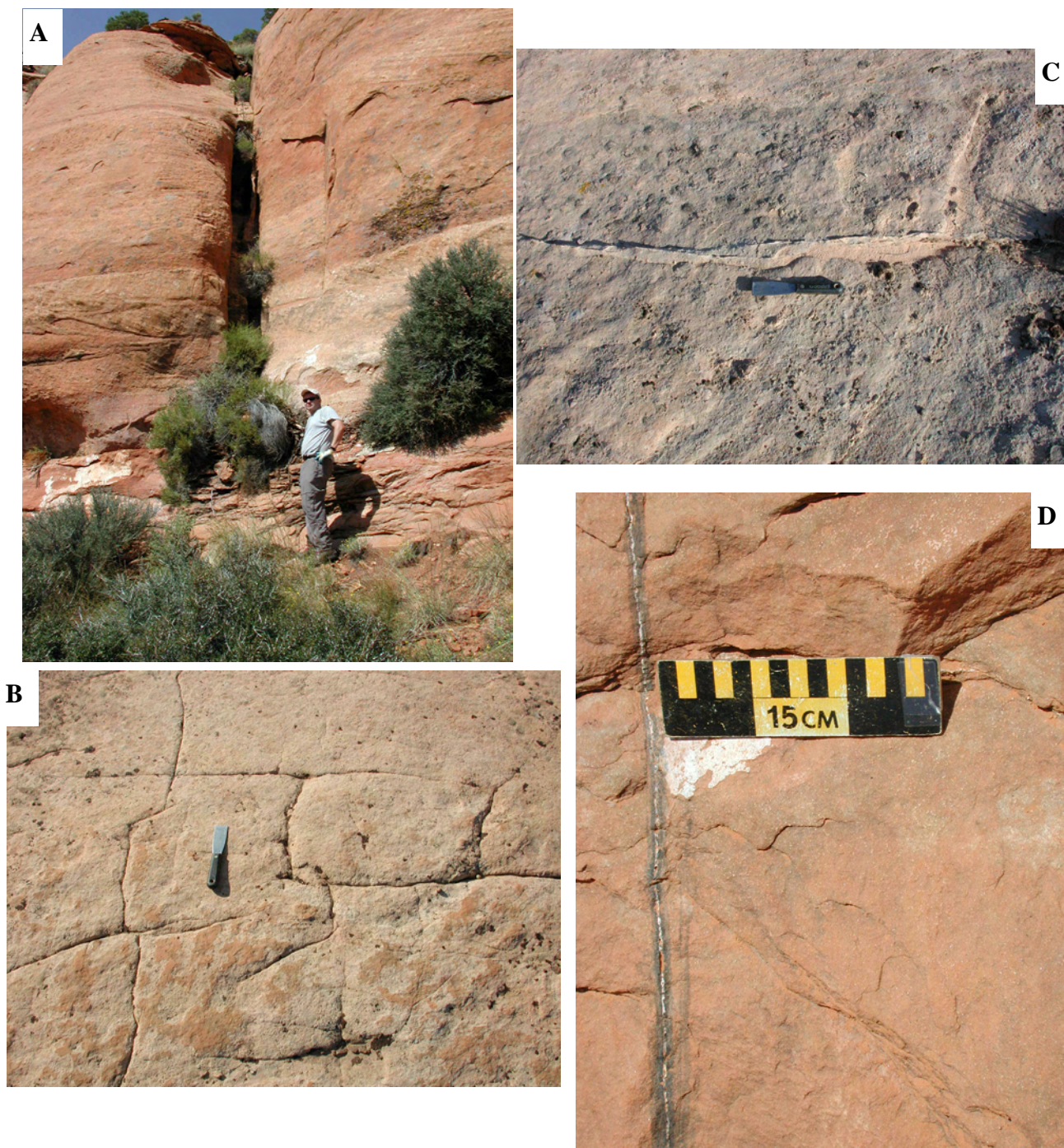


Figure 10. *Examples of joints in the Lisbon field area. (A) Large, probable region-scale joint in the Wingate Sandstone over the gas cap. (B) Blocky or rectilinear joint sets in the Navajo Sandstone over the water leg. (C) Thin silica vein in a joint over the water leg. (D) Very thin calcite vein with a halo of possible iron/manganese-bearing minerals over the gas cap. Figures 10A and 10D are near the Lisbon No. C-910 well (SW1/4SE1/4 section 10, T. 30 S., R. 24 E., SLBL&M); figure 10B and 10C are near the No. 21-4 Federal well (NW1/4NW1/4 section 21, T. 30 S., R. 24 E., SLBL&M).*

In the Lisbon field area, joint orientation in the Wingate Sandstone on the southwest-dipping flank of the Lisbon surface anticline and over the gas cap is dominantly northwest-southeast (figure 11A), parallel to the regional structural trends. In the relatively flat-lying Navajo Sandstone farther southwest of the surface structure and over the oil leg, the dominant joint trend is nearly perpendicular, east-northeast- west-southwest (figure 11B), to the orientation over the gas cap. Joint sets in flat-lying Navajo over the water leg southwest of the field display a dominant east-west orientation (figure 11C), as well as joint sets with similar orientations as over the oil leg and gas cap.

In the Lightning Draw Southeast field area, the Navajo Sandstone is also relatively flat lying. Two sets of joints are found near the Federal No. 1-31 well. Their orientations are generally north-south and northwest-southeast (figure 12A). Two joint sets are also found in the Navajo to the southeast near the Evelyn Chambers Government No. 1 well (NE1/4NE1/4 section 6, T. 31 S., R. 24 E., SLBL&M). Their orientations are generally northwest-southeast and northeast-southwest (figure 12B).

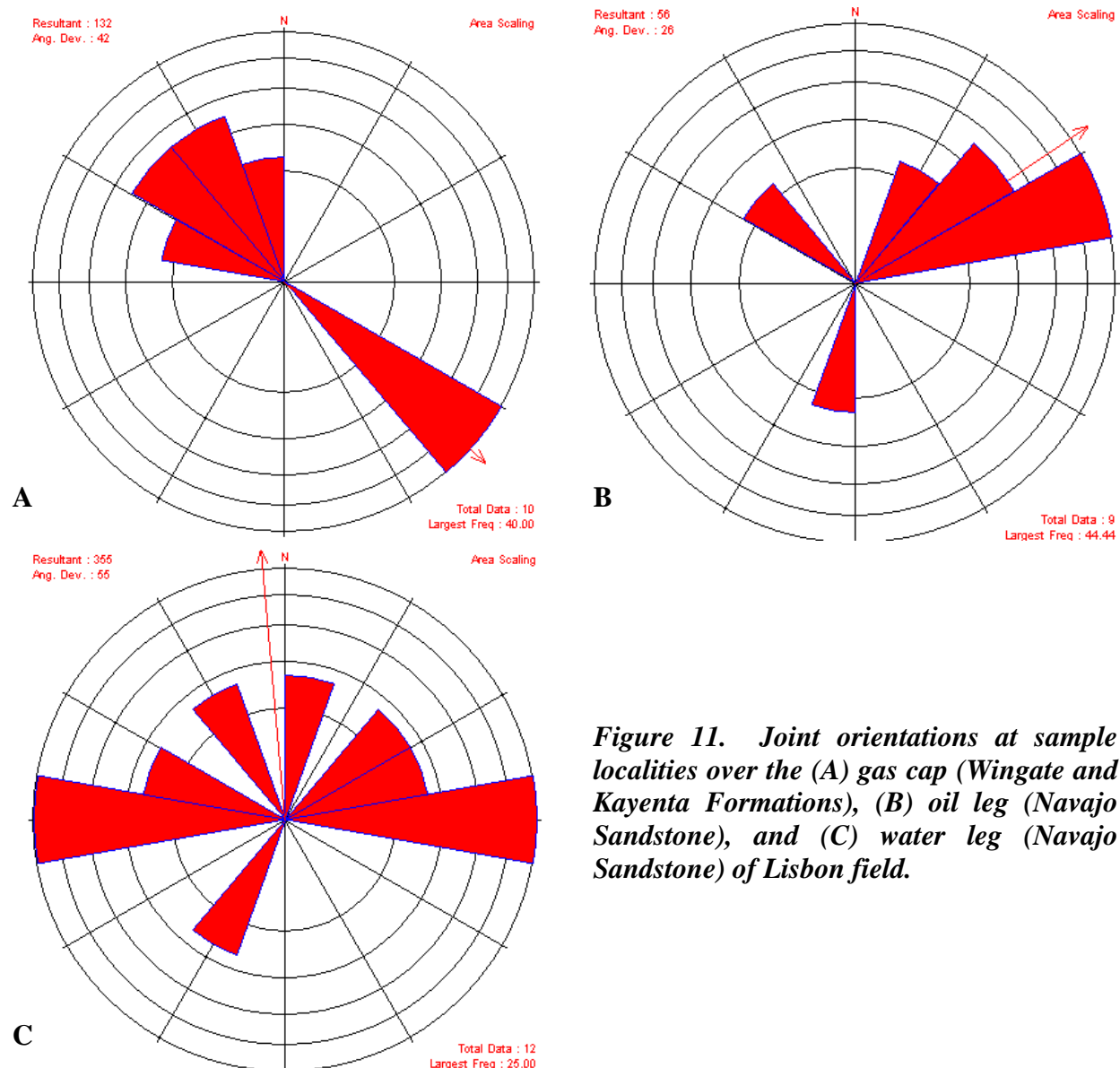


Figure 11. Joint orientations at sample localities over the (A) gas cap (Wingate and Kayenta Formations), (B) oil leg (Navajo Sandstone), and (C) water leg (Navajo Sandstone) of Lisbon field.

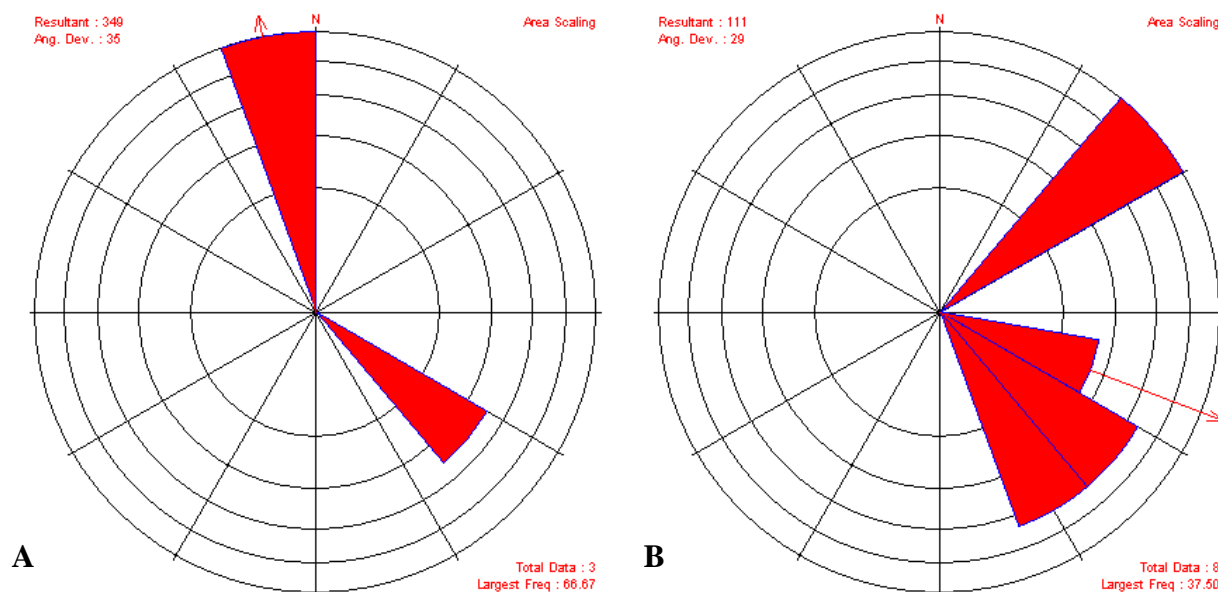


Figure 12. Joint orientations at sample localities near the (A) Federal No. 1-31 well (NW1/4SW1/4 section 31, T. 30 S., R. 24 E., SLBL&M), and (B) Evelyn Chambers Government No. 1 well (NE1/4NE1/4 section 6, T. 31 S., R. 24 E., SLBL&M) at Lightning Draw Southeast field.

Previous Work

Remote sensing studies over Lisbon field have documented the presence of seep-induced alteration to near-surface soils and sediments (Segal and others, 1986; Merin and Segal, 1989; Segal and Merin, 1989). These studies used Landsat Thematic Mapper (TM) data to recognize the presence of kaolinite as well as reduced iron (bleached redbeds). A ratio of TM bands 2/3 was used to define variations in ferric-iron content, while a band 5/7 ratio was used to highlight variations in clay content. Because vegetation also exhibits high band 2/3 ratio values, it can be confused with bleached rocks. Vegetation also shows high band 5/7 ratio values, which can be confused with clay-rich rocks. A TM band 3/4 ratio was generated to define vegetated areas and reduce the chance for misclassification (Dietmar Schumacher, Geo-Microbial Technologies, written communication, August 3, 2005).

There have been no surface geochemical surveys and analysis published on the Lisbon field area.

Methods

Sample Collection

The geochemical survey consisted of collecting soil samples at 1500-foot (500 m) intervals on a 16-square-mile (42 km²) rectangular grid over and around the Lisbon field, and expanded to include northwest-southeast and northeast-southwest grid lines at Lightning Draw Southeast, to map the spatial distribution of surface hydrocarbon anomalies (figure 13). The sampling grid and lines extend beyond the proven limits of Lisbon and Lightning Draw Southeast fields to establish background readings. The areas chosen sufficiently cover the gas

caps, oil-leg (present only at Lisbon), and background “barren” areas. In addition, samples were collected over gas, oil, and dry wells for analogue matching purposes and to refine the discriminant model for Lisbon and Lightning Draw Southeast fields. Because these samples were collected only 3 feet (1 m) apart, they are essentially field duplicates, and can therefore be used to monitor within-site variation.

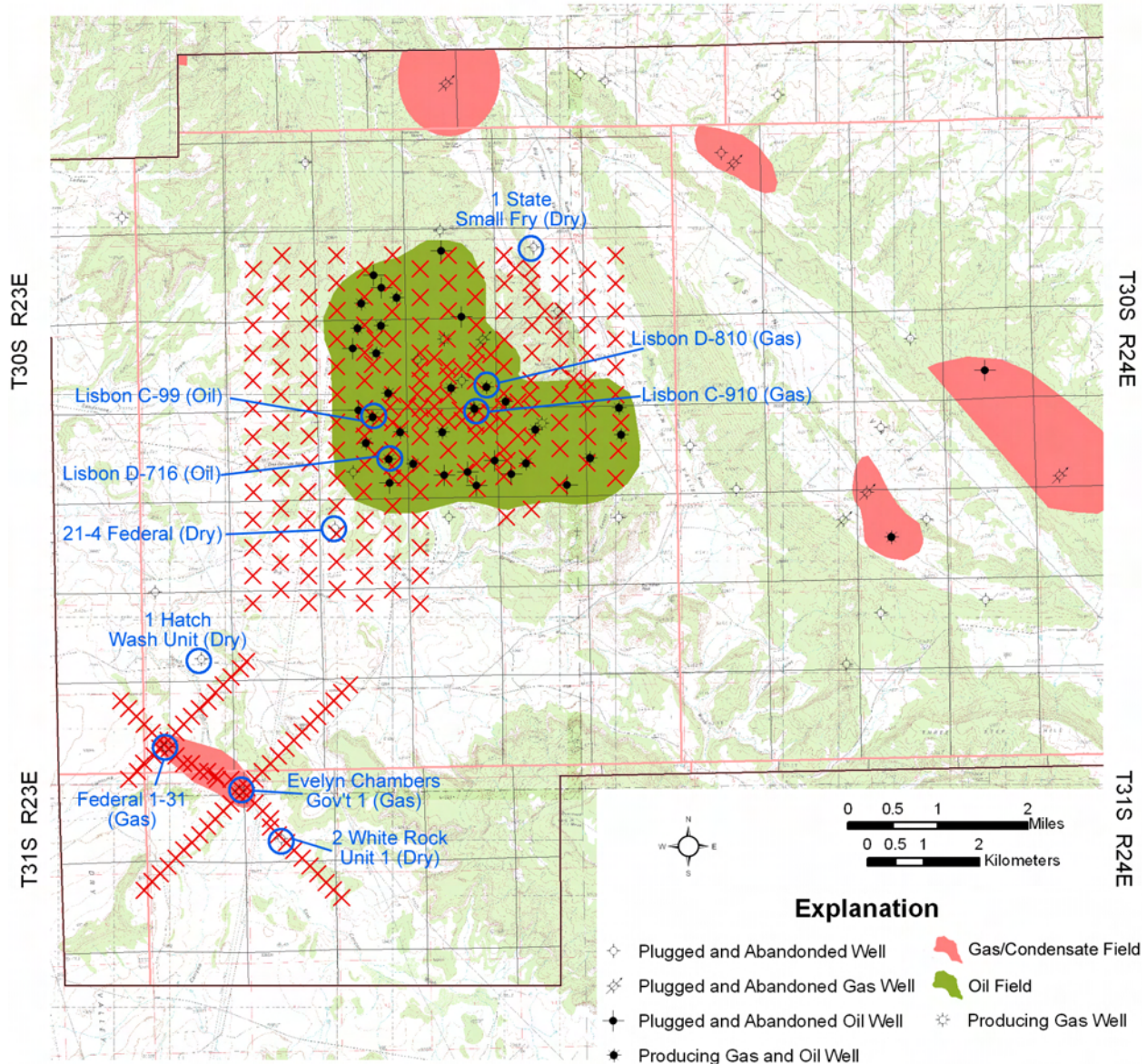


Figure 13. Sampling grid for the surface geochemical survey over Lisbon and Lightning Draw Southeast fields, San Juan County, Utah. Red Xs represent sample locations. About 270 shallow soil samples were collected at 1500-foot intervals over an area of 16 square miles at Lisbon and along northwest-southeast and northeast-southwest grid lines at Lightning Draw Southeast. During the initial phase of the survey, 135 samples were collected around selected gas, oil, and dry wells over the gas caps, oil leg (present only at Lisbon), and water legs of the fields (10 to 15 samples at each of 10 wells [large blue circles]). Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

Along the grid and lines, shallow (generally 8- to 12-inch [20-30 cm] deep) soil samples were collected with a spade or tree-planting shovel over a 6-foot area (2 m) at each site (figure 14A). Care was taken to avoid sampling material sluffed off the surface. The soils were placed and stored in airtight, Teflon-sealed glass soil jars to prevent hydrocarbon contamination during transport to the laboratory in Golden, Colorado. Backup samples were also collected from each site and stored in plastic bags. Some sampling locations required adjustments due to a lack of soil (rock outcrop). Evidence of surface alteration that could be attributed to hydrocarbon seepage and fracturing was also noted. Sample sites around wells were located topographically high relative to the well pad to reduce the possibility of contamination.

Soil samples from joints required the same amount of sample material as was taken along the grid, but they were harder to acquire. Representative samples were often only obtained by scraping sandy soil out of the joints with a stainless steel spoon, knife, or flathead screwdriver (figure 14B). Where the joints were narrow and the soil zone especially shallow, this process frequently required sampling along tens of feet in order to acquire enough material. Places in the joints with established vegetation created sites with deeper soils and better sampling opportunities. Bryophytes and lichen were usually present along most thin-width joints and easily obtained with a small paint scraper or knife (figure 14B).

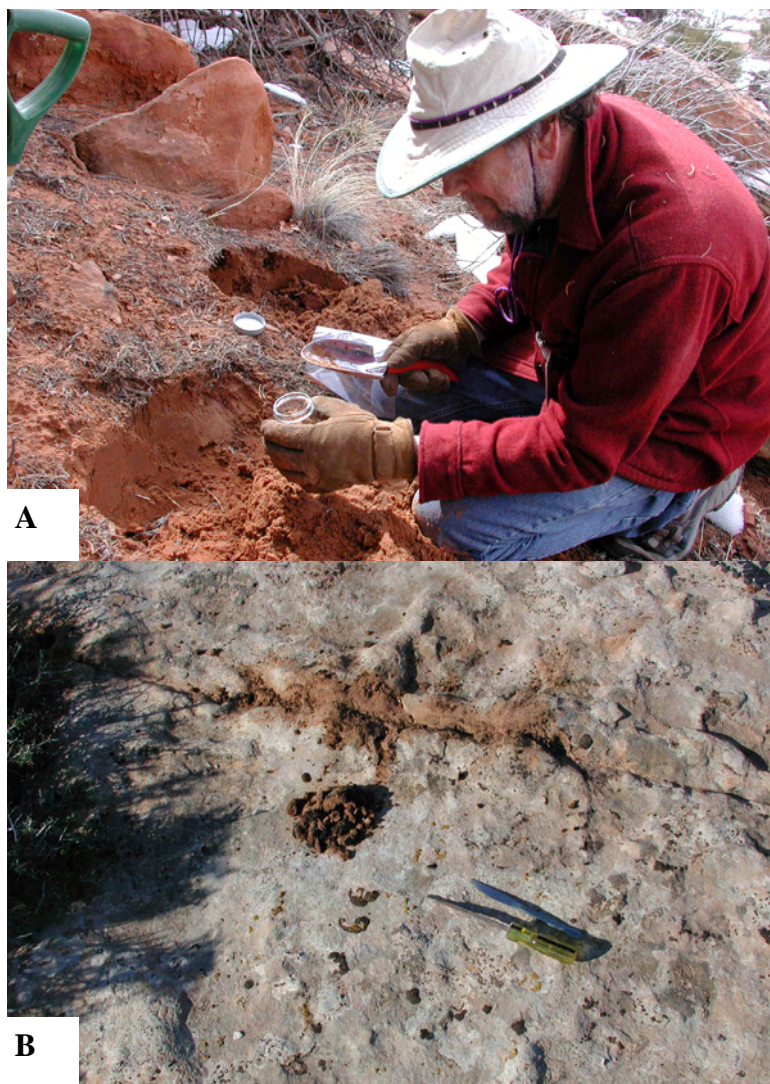


Figure 14. Sampling methods used in the Lisbon area. (A) Collection of shallow sandy soil from 8- to 12-inch depth on Wingate Sandstone outcrop. (B) Along joints, soil, sand, bryophytes, and lichen were sampled using a flathead screwdriver, knife, or stainless steel spoon.

Free-gas samples were collected over Lightning Draw Southeast field and known non-productive areas off the structure (figure 15). Steps for collecting the free gas were as follows:

1. Drill to at least 6-foot (2 m) depth (10 feet [3 m] preferably) in unconsolidated overburden using the Geoprobe percussion (hammer) drill with 1-inch diameter rod (figure 16A).
2. Polyethylene tubing is then inserted into rod and is secured to a retractable point at the bottom of the rod.
3. The soil air is purged at least three times to clear the tubing of ambient air using a plastic syringe (figure 16B).
4. Soil air (free gas) drawn up using the syringe (figure 16B) is then forced into a 1-liter Tedlar bag (for hydrocarbon and fixed gas analyses) and/or lead-lined CO₂ cartridge (for helium analysis). The Tedlar bagged samples are then transported to the laboratory in Golden, Colorado.

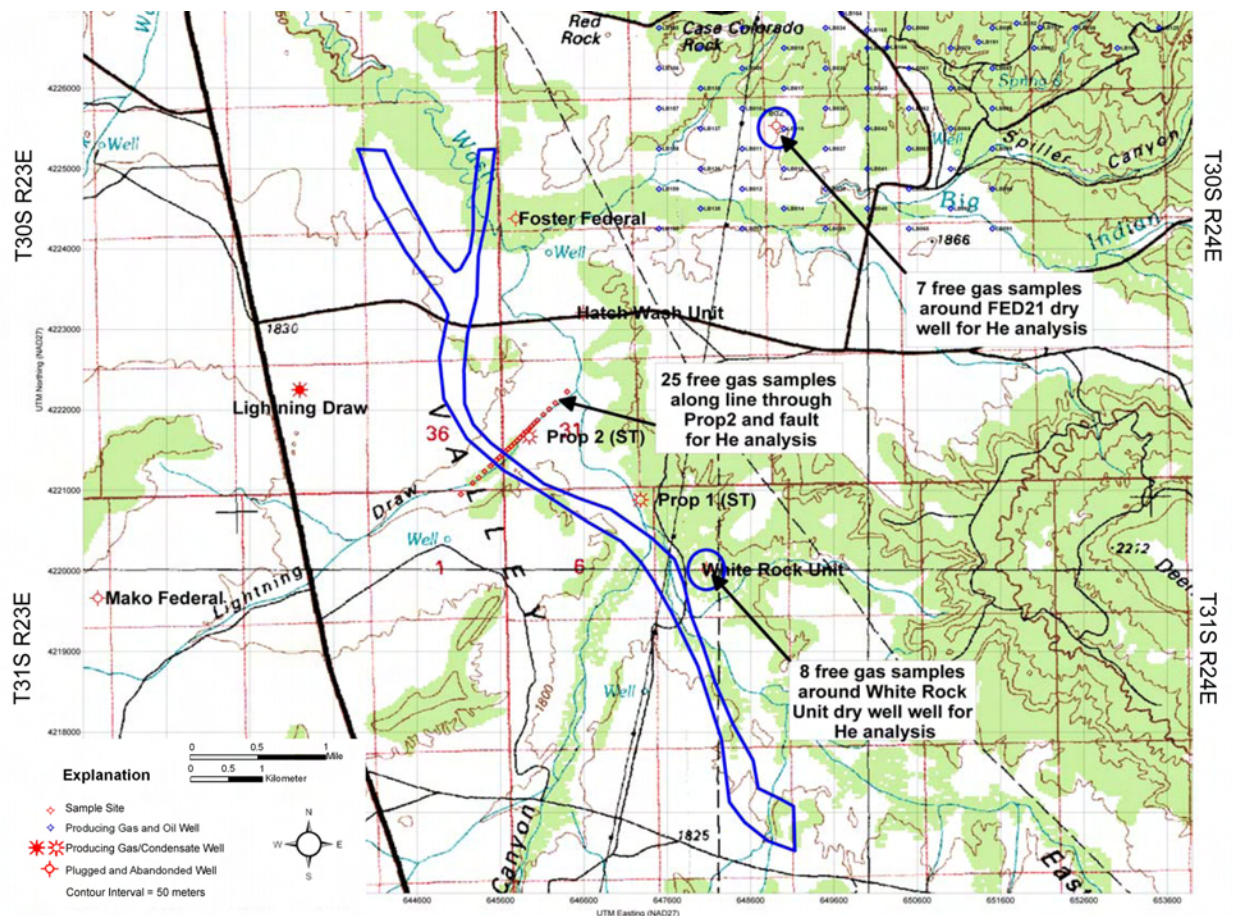


Figure 15. Topographic map showing the location of the free-gas sample sites in Lightning Draw Southeast field and surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.



Figure 16. *Extraction of free gas in the Lightning Draw Southeast field area. (A) Drilling 6-foot holes using the Geoprobe percussion (hammer) drill with 1-inch diameter rod. (B) Polyethylene tubing inserted into rod, and soil air is purged and soil air (free gas) drawn up using a plastic syringe.*

All sample site location coordinates were recorded in the field notes and marked on a Global Positioning System (GPS). Prior to the survey, all sample site coordinates were generated in Garmin-compatible format for uploading to the GPS.

Laboratory Analysis

The soil, bryophytes, and lichen samples are prepared (dried, sieved to <63 microns, thermally desorbed) and the headspace gas analyzed using Direct Geochemical's proprietary techniques for 40 hydrocarbon compounds in the C_1 - C_{12} range, 53 major and trace elements, and seven anion species (table 1). In addition to previously tested techniques, Synchronous Scanned Fluorescence analysis (five fluorescence intensities at specific wavelengths) is also being applied to solvent extracts (for heavy aromatic compounds) of the soil samples to match seepage with produced oil at Lisbon (table 1). Oils with different gravities fluoresce at different wavelengths according to the number of contained aromatic ring compounds as shown by the examples in figure 17.

The free-gas samples are drawn from the Tedlar bag and analyzed for 19 hydrocarbons in the C_1 - C_8 range using a gas chromatograph with a flame ionization detector (GC-FID). Carbon dioxide, CO , O_2 , N_2 , and H_2 are analyzed using a gas chromatograph with a thermal conductivity detector (GC-TCD). Gas from the lead-lined cartridges is analyzed for helium using a micro TCD.

Table 1. Analytes reported by four analytical methods.

C ₁ -C ₁₂ Hydrocarbons	Seven Anions	53 Major and Trace Elements	Synchronous Scanned Fluorescence
methane, ethane, ethene, propane, propene, i-butane, n-butane, butene, i-pentane, n-pentane, pentene, i-hexane, n-hexane, hexene, i-heptane, n-heptane, heptene, i-octane, n-octane, benzene, n-butylbenzene, cyclohexane, n-decane, n-dodecane, ethylbenzene, m-ethyltoluene, p-ethyltoluene, indane, naphthalene, n-nonane, n-propylbenzene, 1,2,4,5-tetramethylbenzene, toluene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, n-undecane, m-xylene, p-xylene, and o-xylene.	fluoride, chloride, bromide, nitrite, nitrate, phosphate, sulfate	Ag, Al, As, Au, B, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, I, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Pd, Pt, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, Zr	Fluorescence intensities in the 250 to 500 nm range that correspond to condensate, medium-gravity oil, and low-gravity oil. Allows fingerprint matching with produced oils in the area.

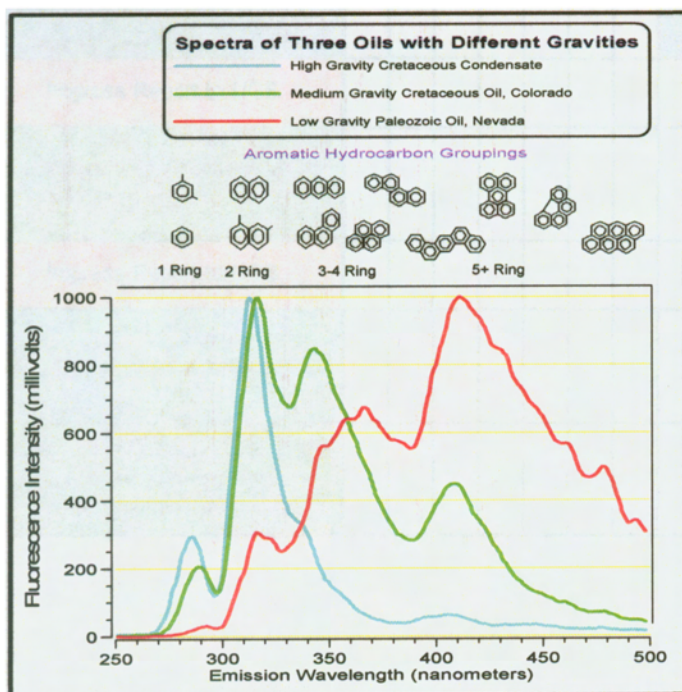


Figure 17. Synchronous Scanned Fluorescence spectra from three oils with different gravities. Courtesy of Direct Geochemical.

Interpretation and Mapping

The data will be compiled in spreadsheets for interpretation purposes. Sample results will be plotted and contoured to identify any surficial geochemical anomalies. The field and analytical precision will be evaluated through calculation of relative standard deviations (RSD's), and these RSD's compared with the total variance to ensure that between-site variance exceeds within-site variance. If these initial variance tests pass, then the data will be interpreted using standard methods. If the data distributions are significantly skewed, then they will be transformed into normality (logarithmic or other) following extreme outlier rejection. The variables may be normalized to Z-scores to better evaluate anomaly contrast in the data.

Probability plots (cumulative frequency distributions) may also be used to find breakpoints in populations between anomalous and background conditions. The Z-scores of individual compounds or elements may be plotted as contour maps or proportional symbol plots.

Multivariate statistical techniques will be applied to attempt to discriminate between hydrocarbon microseepage over productive and non-productive areas. Factor and discriminant analysis will be used to measure the covariance of several variables in multidimensional space simultaneously.

Work to Date

Sample Collection

Permission was obtained from the field operator, EnCana Oil & Gas (USA) Inc., and the U.S. Bureau of Land Management to conduct the surface geochemical sampling program in the Lisbon field area. Encana provided a safety orientation at the Lisbon Gas Plant, and the sampling crew carried a hydrogen sulfide (H₂S) monitor. Some sampling sites were relocated and the grid adjusted farther to the west to avoid an H₂S pipeline in the field.

Approximately 200 soil samples were collected on a grid over Lisbon field and 80 samples along northwest-southeast and northeast-southwest grid lines through Lightning Draw Southeast field (figure 13). Over 60 soil, sand, bryophytes, and lichen samples were collected along joints in the field areas (figure 18).

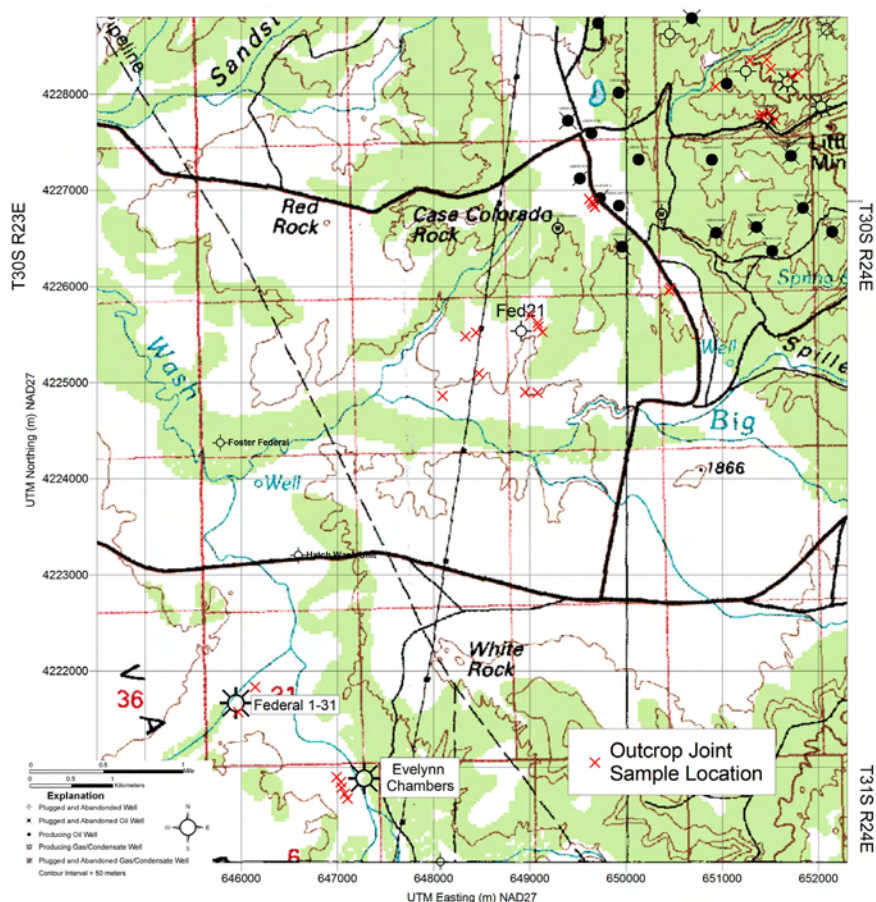


Figure 18. Topographic map showing the location of the outcrop joint sample sites in Lisbon and Lightning Draw Southeast fields and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

Forty free-gas samples were collected in the Lightning Draw Southeast field and surrounding area (figure 15). Twenty-five free-gas samples were collected along a northeast-southwest-trending line through the Federal No. 1-31 well. The sampling line was designed to test the area above the main structure and on the footwall of the southwest-bounding reverse fault (figures 7 and 15). Eight free-gas samples were collected from the No. 2 White Rock Unit 1 well (NE1/4SW1/4 section 5, T. 31 S., R. 24 E., SLBL&M), a dry hole on the southeast end of the Lightning Draw Southeast anticline (figure 7 and 15). Seven free-gas samples were collected from the dry No. 21-4 Federal well (NW1/4NW1/4 section 21, T. 30 S., R. 24 E., SLBL&M) to the northeast (figure 15).

Two main soil types were noted over the survey areas. Soil on outcrop consists of patchy, shallow, microbiotic, lichen-covered, fine- to medium-grained sand (Munsell Color = 10YR 6/4). Vegetation on outcrops consists mainly of juniper and pinyon pine. In the flat valleys between outcrops, the soil profile is more continuous, deeper, and finer grained than on outcrops (Munsell Color = 2.5YR 5/6). The soil consists mainly of silt and fine sand of eolian origin. Vegetation in the valleys mainly consists of sagebrush.

At Lisbon field, 90 samples were collected around two gas wells in the gas cap, two productive oil wells in the oil leg, and two barren dry wells (figure 13), 15 samples at each well site. The two gas wells are the Lisbon No. C-910 well (SW1/4SE1/4 section 10, T. 30 S., R. 24 E., SLBL&M), which has produced 23,279 bbls of oil (3700 m³) and 24.5 BCFG (0.69 BCMG), and the Lisbon No. D-810 (NW Lisbon USA No. A-2) well (NE1/4SE1/4 section 10, T. 30 S., R. 24 E., SLBL&M), which has produced 20,542 bbls of oil (3300 m³) and 21.6 BCFG (0.61 BCMG) (Utah Division of Oil, Gas and Mining, 2006). The two oil wells are the Lisbon No. C-99 well (SW1/4SE1/4 section 9, T. 30 S., R. 24 E., SLBL&M), which has produced 502,759 bbls of oil (80,000 m³) and 12.9 BCFG (0.37 BCMG), and the Lisbon No. D-716 well (SW1/4SE1/4 section 10, T. 30 S., R. 24 E., SLBL&M), which has produced 552,265 bbls of oil (88,000 m³) and 10.1 BCFG (0.29 BCMG) (Utah Division of Oil, Gas and Mining, 2006). The barren dry wells include one to the west of the field in the water leg (the No. 21-4 Federal, NW1/4NW1/4 section 21, T. 30 S., R. 24 E., SLBL&M) and the other is northeast of the field on the low side of the fault which parallels the structure (the No. 1 State-Small Fry, NE1/4NW1/4 section 2, T. 30 S., R. 24 E., SLBL&M).

At Lightning Draw Southeast field, 45 samples were collected around two gas wells over the gas cap and two barren dry wells (figure 13), 10 to 15 samples at each well site. The two gas wells are the Federal No. 1-31 well, which has produced 495 bbls of condensate (79 m³) and 0.08 BCFG (0.002 BCMG) (currently shut-in), and the Evelyn Chambers Government No. 1 well, which has produced 1368 bbls of condensate (218 m³) and 0.13 BCFG (0.004 BCMG) (Utah Division of Oil, Gas and Mining, 2006). The barren dry wells include the No. 2 White Rock Unit 1 well and No. 1 Hatch Wash Unit (NW1/4SE1/4 section 30, T. 30 S., R. 24 E., SLBL&M) north of the field in the water leg.

Laboratory Analysis

EnCana provided produced gas composition data from the Lisbon No. C-910 well. In addition, EnCana provided oil samples from Lisbon Nos. D-716 and C-99 (SW1/4SE1/4 section 9, T. 30 S., R. 24 E., SLBL&M) wells for Synchronous Scanned Fluorescence analysis. The current field reservoir pressure is low due to nearly 50 years of production and current blowdown of the gas cap. Although production from the oil wells is relatively small (totaling 18 BOPD [3 CMPD]), they currently represent the best in the field.

The following summarizes the analytical progress as of September 30, 2006, on the soil and free-gas samples collected at Lisbon and Lightning Draw Southeast fields and surrounding areas:

Soils (406 samples collected):

- Anion analysis – completed (0 remaining)
- C₁-C₈ – 406 analyzed (0 remaining)
- C₆-C₁₂ – 87 analyzed (319 remaining)
- SSF – 406 analyzed (0 remaining)
- 53 elements – 0 analyzed (406 remaining)
- Loss on ignition – 406 analyzed (0 remaining)

Free Gas (40 samples collected)

- C₁-C₈ – all completed and reported
- Fixed Gases (CO₂, O₂, He, H₂) – all completed and reported

Results

Productive and non-productive areas can be distinguished based on absolute concentrations of propane, isobutane, normal butane, isopentane, normal pentane, isohexane, hydrogen, and carbon dioxide in free-gas samples collected over the Lightning Draw Southeast field anticline, across the fault that parallels the southwest flank of the structure, and near downdip wells (figures 19 through 26). Essentially no hydrocarbon shows were recorded around dry wells. Samples from the transect through the Federal No. 1-31 well show 50 to 1100 parts per billion per volume of gas sampled (ppb/v) for propane, 50 to 1600 ppb/v isobutane, and 70 to 1000 ppb/v for normal butane and isopentane, 50 to 300 ppb/v for normal pentane, and 50 to 200 ppb/v for hexane. One sample site near the projected trace of the southwest-bounding fault shows 35 to 70 ppb/v normal butane, suggesting possible seepage associated with the fault zone. Samples from the transect through the Federal No. 1-31 well and the White Rock Unit No. 1 show 10 to 50 parts per million (ppm) for hydrogen and 4000 to 8000 ppm carbon dioxide; all other samples along the transect show 3 to 10 ppm for hydrogen and 1300 to 4000 ppm carbon dioxide. Understanding the sources of the hydrogen and carbon dioxide requires further investigation.

Microseepage in soils over productive and non-productive areas is also different in terms of Synchronous Scanned Fluorescence spectral patterns. The discriminant function separating microseepage over these areas correctly predicts the location of the production at Lightning Draw Southeast field. Sulfate and chloride increase along suspected faults near production, which probably reflects the ascent (paleo?) of brines to the surface from the underlying Pennsylvanian Paradox Formation.

TECHNOLOGY TRANSFER

The UGS is the Principal Investigator and prime contractor for the Leadville Limestone project, described in this report. All maps, cross sections, lab analyses, reports, databases, and other deliverables produced for the project will be published in interactive, menu-driven digital

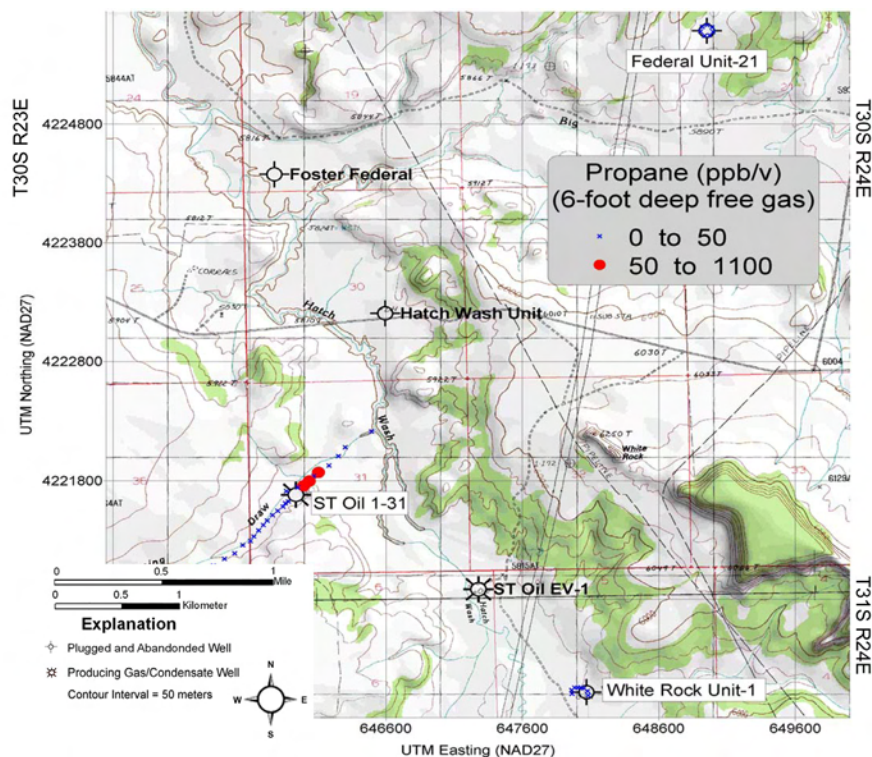


Figure 19. Absolute concentration (ppb/v) of propane in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

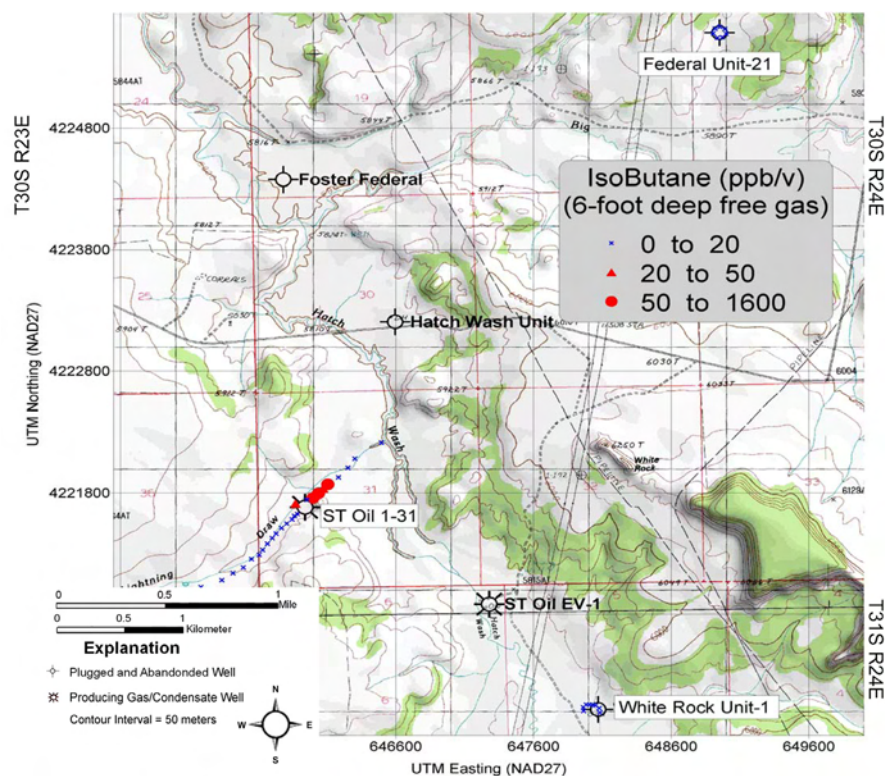


Figure 20. Absolute concentration (ppb/v) of isobutane in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

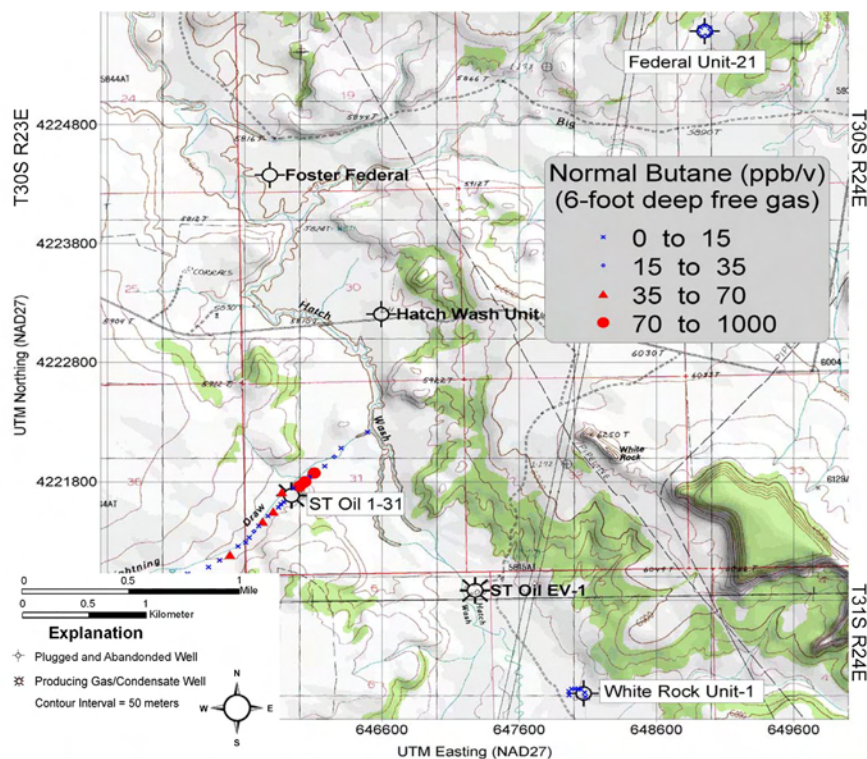


Figure 21. Absolute concentration (ppb/v) of normal butane in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

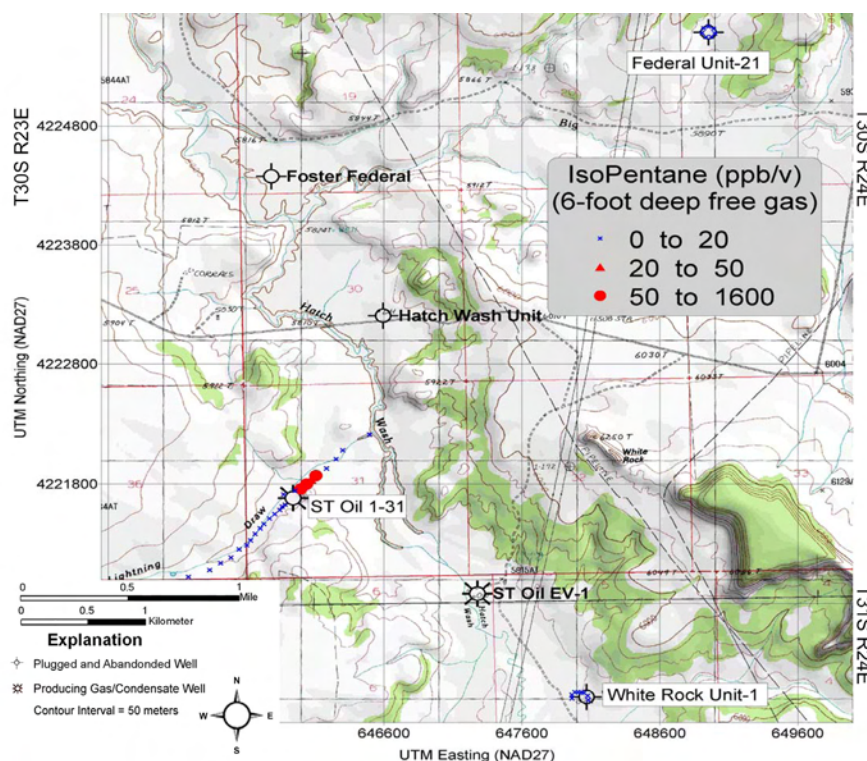


Figure 22. Absolute concentration (ppb/v) of isopentane in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

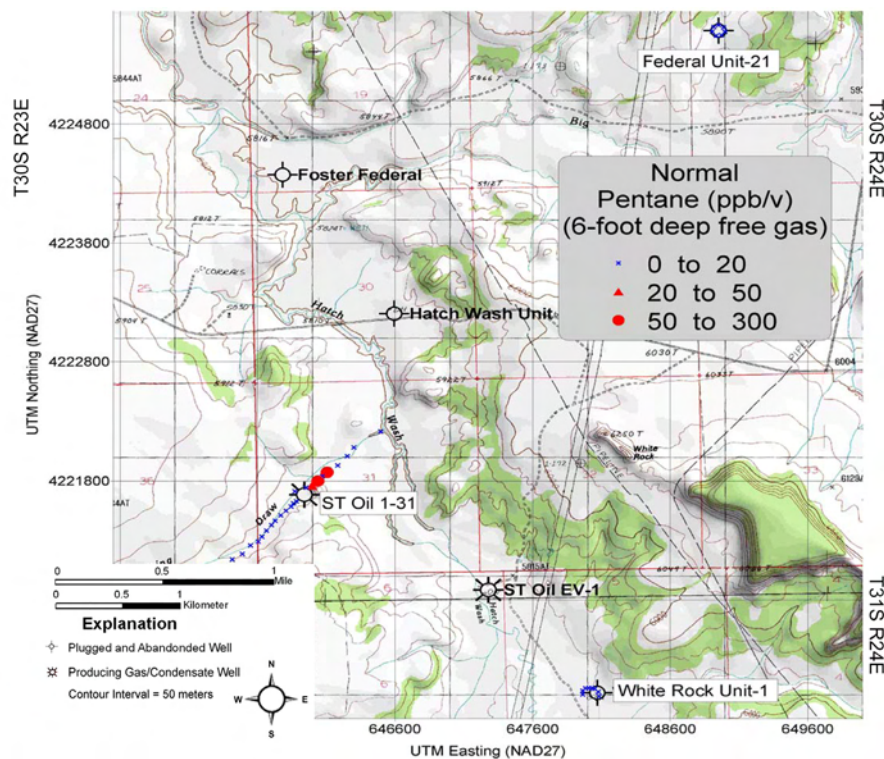


Figure 23. Absolute concentration (ppb/v) of normal pentane in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

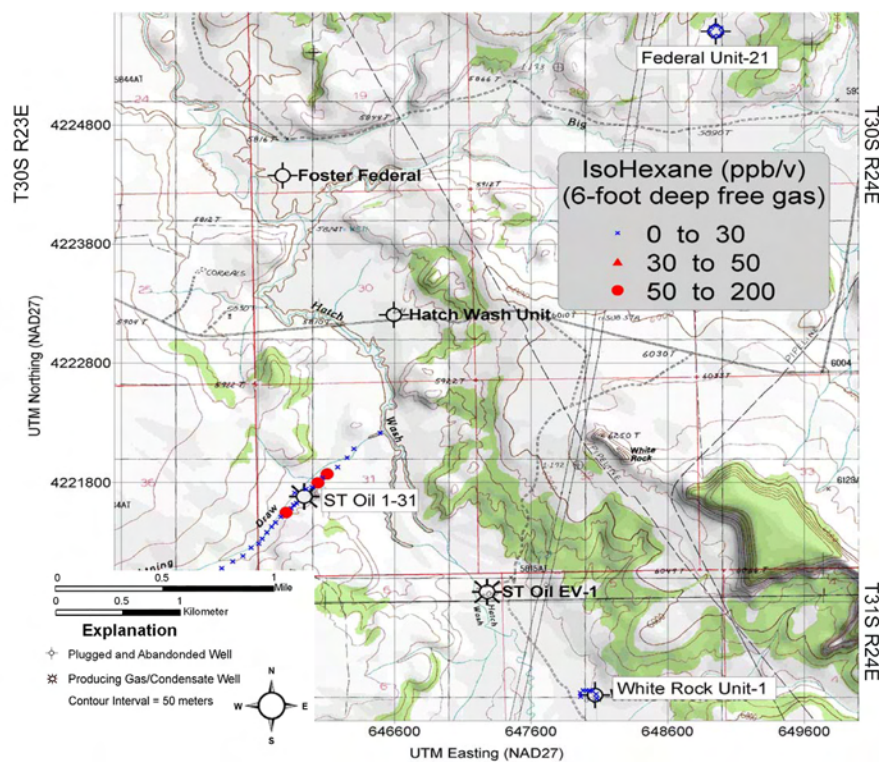


Figure 24. Absolute concentration (ppb/v) of isoHexane in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

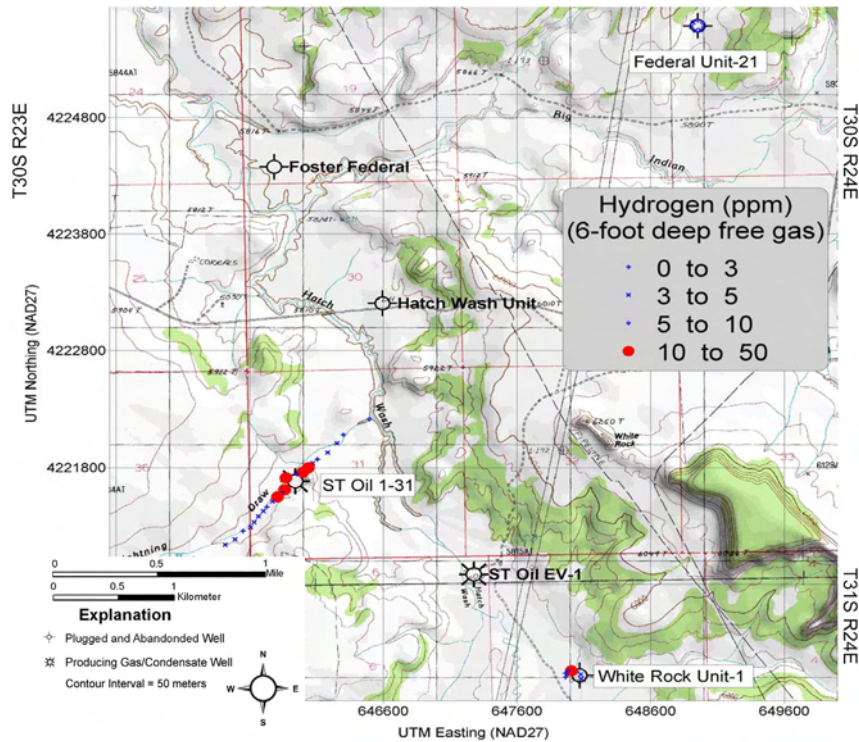


Figure 25. Absolute concentration (ppm) of hydrogen in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

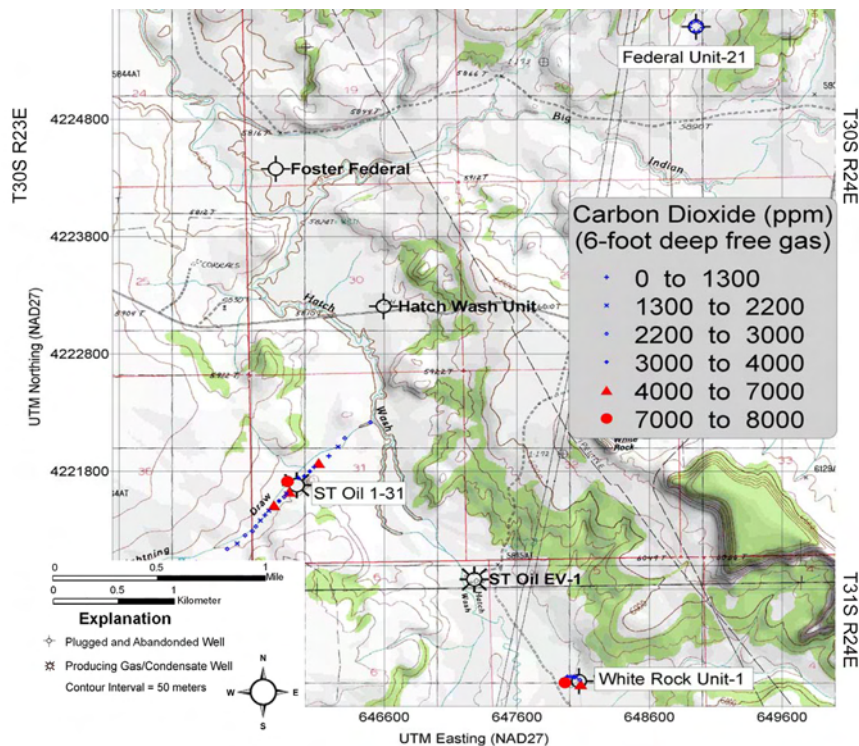


Figure 26. Absolute concentration (ppm) of carbon dioxide in free gas samples collected over the Lightning Draw Southeast field anticline and the surrounding area. Base map: La Sal 30X60' topographic quadrangle map, U.S. Geological Survey.

(Web-based and compact disc) and hard-copy formats by the UGS for presentation to the petroleum industry. Syntheses and highlights will be submitted to refereed journals, as appropriate, such as the *American Association of Petroleum Geologists (AAPG) Bulletin* and *Journal of Petroleum Technology*, and to trade publications such as the *Oil and Gas Journal*. This information will also be released through the UGS periodical *Survey Notes* and be posted on the UGS Paradox Basin project Web page.

The technology-transfer plan includes the formation of a Technical Advisory Board and a Stake Holders Board. These boards meet annually with the project technical team members. The Technical Advisory Board advises the technical team on the direction of study, reviews technical progress, recommends changes and additions to the study, and provides data. The Technical Advisory Board is composed of Leadville field operators and those who are actively exploring for Leadville hydrocarbons in Utah and Colorado. This board ensures direct communication of the study methods and results to the operators. The Stake Holders Board is composed of groups that have a financial interest in the study area including representatives from the State of Utah (School and Institutional Trust Lands Administration, and Utah Division of Oil, Gas and Mining) and the federal government (Bureau of Land Management). The members of the Technical Advisory and Stake Holders Boards receive all semi-annual technical reports, copies of all publications, and other material resulting from the study. Board members also provide field and reservoir data.

Project materials, plans, objectives, and results were displayed at the UGS booth during the AAPG Annual Convention, April 9-12, 2006, in Houston, Texas, and at the AAPG Rocky Mountain Section Meeting, June 10-13, 2006, in Billings, Montana. Four UGS scientists staffed the display booth at these events. Project displays will be included as part of the UGS booth at professional meetings throughout the duration of the project.

An abstract describing the surface geochemical survey and results was submitted to the AAPG, for a possible presentation at the 2007 Annual Convention in Long Beach, California.

Utah Geological Survey *Survey Notes* and Web Site

The UGS publication *Survey Notes* provides non-technical information on contemporary geologic topics, issues, events, and ongoing UGS projects to Utah's geologic community, educators, state and local officials and other decision-makers, and the public. *Survey Notes* is published three times yearly. Single copies are distributed free of charge and reproduction (with recognition of source) is encouraged. The UGS maintains a database that includes those companies or individuals specifically interested in the Leadville project or other DOE-sponsored UGS projects. They receive *Survey Notes* and notification of project publications and workshops.

The UGS maintains a Web site on the Internet, <http://geology.utah.gov>. The UGS site includes a page under the heading *Oil, Gas, Coal, & CO₂*, which describes the UGS/DOE cooperative studies past and present (PUMPII, Paradox Basin [two projects evaluating the Pennsylvanian Paradox Formation], Ferron Sandstone, Bluebell field, Green River Formation), and has a link to the DOE Web site. Each UGS/DOE cooperative study also has its own separate page on the UGS Web site. The Leadville Limestone project page, <http://geology.utah.gov/emp/leadville/index.htm>, contains (1) a project location map, (2) a description of the project, (3) a reference list of all publications that are a direct result of the project, (4) poster presentations, and (5) semi-annual technical progress reports.

Presentations

The following presentations were made during the reporting period as part of the technology transfer activities:

“Major Oil Plays in San Juan County” by Roger L. Bon, May 15, 2006, to the San Juan County Commissioners and general public, Monticello, Utah. The petroleum geology of the Paradox Basin, play potentials, land-use issues, and the economic impact on the county were the focus of the discussion.

“Utah’s Petroleum Systems, Enhanced Oil Recovery, and Opportunities for CO₂ Sequestration” by Rick Allis, May 23, 2006, at the Interstate Oil & Gas Compact Commission Midyear Issues Summit, Billings, Montana. Utah’s exploration history and an overview of the petroleum geology of the major plays and their potential were part of the presentation.

Project Publication

Chidsey, T.C., Jr., Gwynn, J.W., Morgan, C.D., Vanden Berg, M.D., and Seneshen, D.M., 2006, The Mississippian Leadville Limestone exploration play, Utah and Colorado: exploration techniques and studies for independents – semi-annual technical progress report for the period October 1, 2005 to March 31, 2006: U.S. Department of Energy, DOE/BC15424-5, 43 p.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

1. The Mississippian Leadville Limestone is a shallow, open-marine, carbonate-shelf deposit. The Leadville has produced over 53 million barrels (8.4 million m³) of oil from seven fields in the Paradox fold and fault belt of the Paradox Basin, Utah and Colorado. Most Leadville oil and gas production is from basement-involved structural traps. All of these fields are currently operated by small, independent producers. This environmentally sensitive, 7500-square-mile (19,400 km²) area is relatively unexplored. Only independent producers continue to hunt for Leadville oil targets in the region.
2. Lisbon field accounts for most of the Leadville oil production in the Paradox Basin. Its reservoir characteristics, particularly diagenetic overprinting and history, and Leadville facies can be applied regionally to other fields and exploration trends in the basin (including the recently discovered Lightning Draw Southeast field to the southwest). Therefore, Lisbon field was selected as the case-study field for the Leadville Limestone project.
3. Surface geochemical surveys have proved to help identify areas of poorly drained or by-passed oil in other basins. Lisbon field is ideal for a surface geochemical survey because proven hydrocarbons underlie the area, sample sites are relatively easily

accessible, and the surface geology is similar to the structure of the field. Lisbon field is the largest Leadville producer and is still actively producing oil and gas. The surface geology at Lisbon field consists of a major anticline along a large normal fault. Proving the success of relatively low-cost geochemical surveys at Lisbon field will allow independent operators to reduce risks and minimize impacts on environmentally sensitive areas while exploring for Leadville targets.

4. The geochemical survey consisted of collecting about 200 shallow soil samples at 1500-foot intervals (500 m) on a 16-square-mile (42 km²) rectangular grid over and around the Lisbon field to map the spatial distribution of surface hydrocarbon anomalies. The sampling grid extends beyond the proven limits of Lisbon field to establish background readings. The area chosen sufficiently covers the oil-leg, gas cap, and background barren areas. In addition, 90 samples were collected over gas, oil, and dry wells for analogue matching purposes and to refine the discriminant model for Lisbon field.
5. To the southwest, the recently discovered Lightning Draw Southeast field has similar geology to Lisbon field, both in terms of structure and a Leadville reservoir. It consists of two producing wells, primarily gas and condensate, along with barren dry wells off structure. However, the field is still near original reservoir pressure and therefore hydrocarbon microseepage to the surface may be more significant than at Lisbon field. The surface geochemical survey was expanded to include this new field and the surrounding area with about 80 samples collected along northwest-southeast and northeast-southwest grid lines and 45 samples around both the producing wells and barren dry wells.
6. The soil samples were placed and stored in airtight, Teflon-sealed glass soil jars to prevent hydrocarbon contamination during transport. Samples were being dried and sieved, and aliquots weighed out for ongoing geochemical analyses for 40 hydrocarbon compounds in the C₁-C₁₂ range, 53 major and trace elements, seven anion species, and for Synchronous Scanned Fluorescence analyses. Sample results will be plotted and contoured to identify any surficial geochemical anomalies.
7. Two main soil types were noted over the survey area. Soil on outcrop consists of patchy, shallow, microbiotic, lichen-covered, fine- to medium-grained sand. In the flat valleys between outcrops, the soil profile is more continuous, deeper, and finer grained than on outcrops, consisting mainly of silt and fine sand of eolian origin.
8. Joints in the Navajo and Entrada Sandstones may provide pathways for hydrocarbon microseepage to the surface. Sandstone outcrops have parallel and polygonal joints filled with soil, sand, bryophytes, and lichen. Over 60 samples were collected along joints for geochemical analyses.
9. Free-gas samples (40) were also collected over Lightning Draw Southeast field and known non-productive areas off the structure. Productive and non-productive areas can be distinguished based on absolute concentrations of propane, isobutane, normal butane, isopentane, normal pentane, isohexane, hydrogen, and carbon dioxide in free-gas

samples. Microseepage in soils is also different in terms of Synchronous Scanned Fluorescence spectral patterns. The discriminant function separating microseepage over productive and non-productive areas correctly predicts the location of the new production at Lightning Draw Southeast field. Sulfate and chloride increase along suspected faults near production, which probably reflects the ascent (paleo?) of brines to the surface from the underlying Pennsylvanian Paradox Formation.

10. Surface geochemical surveys represent a fast, low-cost alternative to 3D seismic acquisition, especially in environmentally sensitive areas with extensive outcrops such as the Paradox Basin. Anomalies are relatively easy to identify and are conclusive.

ACKNOWLEDGMENTS

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